MINERAL STATUS OF SHEEP IN THE PARAMO REGION OF COLOMBIA

BY

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1989

ACKNOWLEDGMENTS

I wish to express my sincere gratitude and appreciation to Dr. Lee R. McDowell, adviser and chairman of my supervisory committee, for his valuable guidance and assistance throughout the investigation and preparation of the present dissertation. Acknowledgments are also due to to Dr. Joseph M. Conrad, Clarence B. Ammerman, Douglas B. Bates and Lynn E. Sollenberger for their time and advice as members of the supervisory committee.

Recognition and appreciation are due to Mrs. Nancy Wilkinson and Mr. Richard Fathiere for their assistance in all laboratory work and to Dr. Frank G. Martin and Dr. Steve Linda for their assistance in statistical analysis.

Special appreciation is due to Dr. Oliver Ospina of Caja Agraria and to Dr. Alfonso Naranjo of Instituto Colombiano Agropecuario (ICA), who permitted the sample collection in order to make this work possible, to Dr. Rodrigo Lora for soil analysis and to Dr. Jorge Naira for whole blood analysis at ICA laboratories.

Special recognition is due to Instituto Colombiano Agropecuario for the financial support of my studies in the United States.

Deep appreciation goes to my wife Diana and to my five children for their companionship and encouragement during this hardship. To them, this dissertation is gratefully dedicated.

TABLE OF CONTENTS

		Page
ACKNOWLEDGMENTS		ii
LIST OF TABLES		vii
LIST OF FIGURES		x
ABSTRACT		xi
CHAPTER		
I	INTRODUCTION	1
II	LITERATURE REVIEW	3
	Characterization of the Sheep Industry in Colombia	3
	Mineral Status of Soil	7
	Soil Acidity and Organic Matter	7
	Soil Macronutrients	10
	Soil Micronutrients	12
	Mineral Status of Plants	16
	Forage Macrominerals	18
	Forage Microminerals	20
	Mineral Status and Requirements of Ruminants	23
	Tissue Macrominerals	23
	Tissue Microminerals	29
	Hematological Measurements	33
III	MATERIALS AND METHODS	36
	Identification and Description of Research	36
	Sample Collection	37
	Soil Samples	37
	Forage Samples	39
	Animal Tissue Samples	40
	Whole blood and blood serum	41
	Bone biopsy	42
	Liver biopsy	43

Page

Chemical Analysis. 43
Soil Samples. 43
Forage Samples. 44
Animal Tissue Samples 45
Blood serum 45
Whole blood. 45
Bone samples. 46
Liver samples. 46
Statistical Analysis 48

IV MINERAL STATUS OF SHEEP IN THE PARAMO REGION OF COLOMBIA: I. MACROELEMENTS 49

Introduction 49
Materials and Methods. 50
Results and Discussion 53
Soil Analyses 53
Forage Analyses 55
Animal Tissue Analyses. 59
Blood serum 60
Bone 64
Correlation Coefficients of Minerals. . . . 66
Hematological Measurements. 67
Summary and Conclusions 69

V MINERAL STATUS OF SHEEP IN THE PARAMO REGION OF COLOMBIA: II. MICROELEMENTS. 71

Introduction 71
Materials and Methods. 72
Results and Discussion 75
Soil Analyses 75
Forage Analyses 78
Animal Tissue Analyses. 82
Blood serum 82
Liver 86
Correlation Coefficients of Minerals. . . . 90
Summary and Conclusions. 90

VI MINERAL CONCENTRATIONS IN LEAVES AND STEMS OF VARIOUS FORAGES OF THE COLOMBIAN PARAMO. 93

Introduction 93
Materials and Methods. 94

Page

Results and Discussion 96
Plant Fractions-Macrominerals, Crude Protein, and IVOMD 96
Plant Fractions-Microminerals 99
Forage Species 102
Soil-Plant Relationship 108
Summary and Conclusions. 110

VII SUMMARY AND CONCLUSIONS. 112

APPENDIX A FIGURES 117

APPENDIX B TABLES. 121

APPENDIX C RAW DATA. 146

LITERATURE CITED. 180

BIOGRAPHICAL SKETCH 192

LIST OF TABLES

Table		Page
I.	CONCENTRATIONS (PPM) OF MINERALS OF DRIED SOIL AND THEIR INTERPRETATION	13
2.	SUMMARY GUIDE TO NINERAL REQUIREMENTS FOR RUMINANTS (DRY BASIS).	17
3.	DIAGNOSIS OF SPECIFIC MINERAL DEFICIENCIES OR TOXICITIES IN SHEEP	24
4.	NORMAL BLOOD HEMOGLOBIN, HEMATOCRIT AND LEUCOCYTE VALUES IN SHEEP	35
5.	SOIL ORGANIC MATTER, pH, AND MACROMINERAL ANALYSES AS RELATED TO SEASON AND FARM (DRY BASIS)	54
6.	FORAGE MACROMINERAL, CRUDE PROTEIN, AND IVOMD CONCENTRATIONS AS RELATED TO SEASON AND FARM (DRY BASIS).	56
7.	BLOOD SERUM AND BONE MACROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND FARM.	61
8.	BLOOD SERUM AND BONE MACROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND ANIMAL CLASS.	62
9.	HEMOGLOBIN, HEMATOCRIT CONCENTRATIONS AND LEUCOCYTE COUNTS AS RELATED TO BEASON AND FARM.	68
10.	SOIL MICROMINERAL ANALYSES AS RELATED TO SEASDN AND FARM DRY EASIS)	76
11.	FORAGE NICROMINERAL CONCENTRATIONS AS RELATED TO BEASDN AND FARM (DRY BASIS).	79
I2.	BLOOD SERUM AND LIVER NICROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND FARM	83
13.	BLOOD SERUM AND LIVER NICRONINERAL CONCENTRATIONS AS RELATED TO SEASON AND ANIMAL CLASS	84

Table		Page
14.	FORAGE MACROMINERAL, CRUDE PROTEIN, AND IVOMD CONCENTRATIONS AS RELATED TO SEASON AND PLANT PART (DRY BASIS).	98
15.	FORAGE MICROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND PLANT PART (DRY BASIS)	100
16.	FORAGE MACROMINERAL, CRUDE PROTEIN, AND IVOMD CONCENTRATIONS BY SPECIES (DRY BASIS).	103
17.	FORAGE MICROMINERAL CONCENTRATIONS BY SPECIES (DRY BASIS).	104
18.	CORRELATION COEFFICIENTS BETWEEN SOIL AND FORAGE MINERALS AS RELATED TO SEASON	109
19.	DESCRIPTION OF FARMS	121
20.	CLIMATE AND AVERAGE MONTHLY RAINFALL (MM)	123
21.	DETAILED NUMBER OF SOIL AND FORAGE COMPOSITE SAMPLES.	124
22.	COMPOSITION OF THE MINERAL MIXTURES.	125
23.	DETAILED NUMBER OF TISSUE SAMPLES	126
24.	SUMMARY OF ANALYSES OF VARIANCE OF SOIL ORGANIC MATTER, PH, AND MACROMINERALS-MEAN SQUARES BY SEASON	127
25.	SUMMARY OF ANALYSES OF VARIANCE OF FORAGE CRUDE PROTEIN, IVOMD, AND MICROMINERALS-MEAN SQUARES BY SEASON	128
26.	SUMMARY OF ANALYSES OF VARIANCE OF BLOOD SERUM AND BONE MACROMINERALS-MEAN SQUARES BY SEASON.	129
27.	SUMMARY OF ANALYSIS OF VARIANCE OF WHOLE BLOOD VARIABLES--MEAN SQUARES BY SEASON.	130
28.	BLOOD SERUM AND BONE MACROMINERAL CORRELATION COEFFICIENTS AS RELATED TO SEASON.	131
29.	CORRELATION COEFFICIENTS BETWEEN BLOOD SERUM, LIVER, AND BONE MINERALS AS RELATED TO SEASON.	132

Table Page

30. SUMMARY OF ANALYSES OF VARIANCE OF SOIL MICROMINERALS-MEAN SQUARES BY SEASON . . . 133

31. SUMMARY OF ANALYSES OF VARIANCE OF FORAGE MICROMINERALS--MEAN SQUARES BY SEASON . . . 134

32. SUMMARY OF ANALYSES OF VANIANCE OF BLOOD SERUM AND LIVER MICROMINERALS-MEAN SQUARES BY SEASON . 135

33. SUMMARY OF ANALYSES OF VARIANCE OF FORAGE (PARTS), CRUDE PROTEIN, IVOMD, AND MACROMINERALS-MEAN SQUARES BY SEASON. 136

34. SUMMARY OF ANALYSES OF VARIANCE OF FORAGE (PARTS) MICROMINERALS-MEAN SQUARES BY SEASON 137

35. FORAGE MACROMINERAL, CRUDE PROTEIN, AND IVOMD CONCENTRATIONS AS RELATED TO SEASON AND SPECIES (DRY BASIS). 138

36. FORAGE MICROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND SPECIES (DRY BASIS) 140

37. OVERALL FORAGE MINERAL CONCENTRATIONS IN DIFFERENT SPECIES (DRY BASIS) 142

38. SOIL ORGANIC MATTER, PH, MACROMINERAL AND MICROMINERAL CORRELATION COEFFICIENTS AS RELATED TO SEASON. 143

39. FORAGE MACROMINERAL, MICROMINERAL, CRUDE PROTEIN, ARD IVOMD CORRELATION COEFFICIENTS AS RELATED TO SEASON 144

LIST OF FIGURES

Figure | Page

1. COLOMBIA, GEOGRAPHICAL LOCATION OF THE THREE SHEEP FARMS SURVEYED 117

2. THE PARAMO REGION IN COLOMBIA. 118

Abstract of Dissertation Presented to the Graduate School of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

MINERAL STATUS OF SHEEP IN THE PARAMO REGION OF COLOMBIA

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December 1989

Chairman: Dr. Lee R. McDowell
Major Department: Animal Science

A study was conducted in the paramo region of Colombia to determine the mineral status of grazing sheep by evaluating mineral concentrations in soil, plant, and animal tissues. Samples were taken at the end of the rainy season (May-June, 1987) and at the end of the dry season (February, 1988) from lactating (or pregnant) ewes, lambs, and yearlings. A total of 123 composite soil, 131 composite forage, 207 blood serum, 182 whole blood, 148 bone rib biopsy, and 113 liver biopsy samples were obtained.

Percentage of soil samples that were deficient was selenium 100%, boron 83%, magnesium 70%, manganese 54%, and potassium 52%. Percentage of forage samples that were deficient was sodium 93%, cobalt 87%, copper 75%, selenium 58%, magnesium 53%, and crude protein 8%. None of the values for molybdenum were above the toxic limit of 8 ppm for sheep, and the copper:molybdenum ratio was at least 4:1.

Iron and manganese were in excess of the requirements but below the maximum tolerable levels for sheep. Leaves had higher (P<.05) concentrations of calcium, phosphorus, magnesium, potassium, iron, molybdenum and crude protein than stems. Among soil minerals and the corresponding forage minerals, only calcium and magnesium had positive correlation coefficients (P<.05, r>|.50|) for both seasons.

Serum showed phosphorus deficiency in 59% of the samples during both seasons, and calcium 94% during the dry season. Both calcium and phosphorus were deficient in 98% of bone samples. Liver indicated a copper deficiency in 59% of the samples, and of zinc in 44%: during the dry season 55% were deficient in cobalt. Differences (P<.05) among animal classes were found in serum phosphorus in both seasons as was the case for serum magnesium during the dry season and bone ash during the rainy season.

In conclusion, minerals most likely limiting sheep production in the paramo were calcium, phosphorus, magnesium, copper, zinc and cobalt. Supplementation programs should provide the above minerals plus common salt and selenium.

CHAPTER I
INTRODUCTION

Paramo is an ecological concept that refers to the mountainous regions of the humid equatorial Andes above the upper limit of the forest (3,100 m). It is characterized by extreme environmental conditions, acid soil, low atmospheric pressure, low mean temperature, and high humidity. As such, it is an unique phenomenom in our planet, which only occurs in four countries: Colombia, Venezuela, Ecuador, and Costa Rica. The great importance of the paramo in Colombia is that this region is the country's source of water; most of the rivers have their origin in these very high lands. The paramo is covered with shrubs and native grasses, and is better suited for sheep grazing rather than cattle.

About 47% of the sheep population (total population: 2,464,000) are wooled sheep that graze in the mountains. However, sheep production is not very efficient. Feed is in short supply during the dry season, and in general the few forage species that grow in the paramo are considered of low quality and their regrowth is very slow after grazing. Under these conditions, the animals do not consume their nutritional requirements and produce inefficientiy. The poor growth rate of lambs, low fertility in particular of

imported breeds, high mortality, and low wool production are characteristics of sheep in the paramo of Colombia.

As is known, ruminants grazing forages in severely mineral-deficient areas may be more limited by mineral insufficiency than either a lack of protein or energy. Mineral deficiencies or imbalances in soils and forages are often responsible for low production and reproduction among grazing livestock. As grazing livestock usually do not receive mineral supplementation, except for common salt, they must depend almost exclusively upon forages for their requirements. Therefore, supplemental feeding of adequate minerals, which are frequently deficient in paramo forages, may improve this problem.

The objectives of this study were as follows:

1. to establish if specific mineral deficiencies or toxicities exist in the paramo region of Colombia;
2. to compare the seasonal (rainy vs dry) mineral status of soil, forages, and sheep tissues;
3. to evaluate animal tissues at different physiological states of the sheep (lactating-pregnant ewes, lambs, and yearlings); and
4. to study mineral soil-plant-animal interrelationships.

CHAPTER II
LITERATURE REVIEW

Characterization of the Sheep Industry in Colombia

Colombia, the northernmost of all South American republics, is located at the north east corner of South America between 4° 50' to 79° 01' west of the Greenwich Meridian (Instituto Geografico Agustin Codazzi, 1986). The capital of Colombia, Bogota, lies at an altitude of 2,640 m above sea level (Appendix A, Figure 1).

The total area of the country is 1,141,748 Km^2 and, while there is a great variety of geographical areas, the country has been divided in 5 natural regions. The Andes region and its interandean vallays include the high mountain ranges of the three Cordillera chains (Cordilleras Oriental, Central and Occidental), the Macizo de las Andes and the Sierra Nevada. The Coastal plains, both Pacific and Atlentic, and the Savanna (Llanos Orientales) are included in the Llanuras del Pacifico, Llanuras del Caribe, and the Orinoquia regions, respectively. A dry, almost desert zone in the Peninsula de la Guajira is also included in the Caribe region. A tropical jungle is found in the Amazonia region (Instituto Colombiano Agropecuario, 1980).

In general, two different types of sheep, hair and wooled, are found in Colombia, according to two climatic regions. The hair sheep are concentrated in the lowlands with high temperatures all year, which range from 20 to 33°C under both humid and very dry conditions. Hair sheep are well adapted to tropical environments. The African sheep, as hair sheep are known in Colombia, are usually brown, ranging in shade from tan to brown and cherry-red to dark red (Bradford and Fitzhugh, 1983).

The Peninsula de la Guajira holds about 30% of the total sheep population, most of which are hair sheep. The total sheep numbers in the country were estimated to be 2,464,000 in 1982 (Caja Agraria, 1985).

The wooled sheep are found in the mountain regions where temperatures range from 9 to 15° C; in most cases they graze the higher elevations of the mountains, called paramos, where temperatures are lower than 9°C and humid conditions persist. The departamento de Boyaca leads the country in wooled sheep numbers with about 26% of the total sheep population, followed by Cundinamarca with close to 10%. Santander and Narino are also important regions and they both have 11% of the sheep in Colombia (Caja Agraria, 1985).

The predominant type of wooled sheep is the Native or Criolla breed which is well adapted to the harsh environment of the paramo. Importations of Romney, Corriedale, Hampshire, Scottish Blackface and others have occurred in

the last 30 years and substantial crossing of the Criolla has resulted especially with the Romney breed.

In general, the paramo region has not been exploited in a systematic way and its utilization is in its infancy. The production capability of a sheep industry in the paramo is difficult to determine as sheep have to compete not only with technological but also social restrictions, for example, lack of roads, isolation, lack of electricity, and others (Proyecto Ovino Colombo Britanico, 1979). Among the technical restrictions to the sheep industry in the paramo we can mention the poor growth rate of the lambs until weaning; low bodyweights at 6, 12, and 18 months of age; low fertility in particular with imported breeds; high mortality rate due to several causes; and low production of wool of inferior quality. One important restriction is the very low production of forage which can be attributed to cold weather and periods of excess rainfall or drought (Proyecto Ovino Colombo Britanico, 1979).

In a description of the region, Guhl (1982) contends that the paramo is an ecological concept that refers to the mountainous regions of the humid equatorial Andes above the upper limit of the forest (above 3,100 m). The paraso is characterized by extreme environmental conditions, acid soils, low atmospheric pressure, high humidity, low mean temperature (with daily oscilation), and high air dryness. It is also characterized by the elevated soil and air temperatures during the direct solar radiation and by the

sudden and dramatic changes due to the cloudiness during the night. These factors produce frosts and heavy winds during specific times of the year.

The paramo is a unique phenomenom in our planet, which only occurs in four countries, Colombia, Venezuela, and Ecuador. In Costa Rica the climatic effect of elevations at 2,500 m above sea level are comparable to those of the paramos (Robeyo et al., 1988). Very little is yet known about the complex interrelationships that keep animal and plant life and that permit the existence of the paramos. Less is known of the possible utilization of the paramo lands by man.

The landscape in the paramo is not totally homogeneous, and three altitudinal zones may be distinguished: the superparamo on the higher elevations (above 4,200 m), the proper paramo (3,600-4,200 m, and the subparamo on the lower elevations (3,100-3,800 m) (Salamanca, 1986). The paramo region can be observed in appandix A figure 2.

The natural vegetation in the paramo is adapted to withstand cold and dry conditions. Although the paramo is very humid, in some cases the effective rainfall is low (less than 1,000 mm in a year). A permanent fog in combination with low temperatures keeps the relative humidity at an almost 100%. The soils are generally saturated but is difficult for the plants to utilize the water and so they are in a similar situation as if they were in an arid zone (Salamanca, 1986).

Apart from its possible utilization with grazing animals or other forms of agriculture, the great ecological importance of the paramo lies as a source of water. Most of the rivers in Colombia have their origin in these very high lands (Cleef, 1980)

Around 70% of the Colombian population live and work on the mountains. But the mountain has several aspects, and the higher elevations, as are the paramos, become a hostile region to man for its climate and topography, and are natural obstacles to communications (Guhl, 1982).

Mineral Status of Soil

Soil Acidity and Organic Matter

McDowell (1985) indicates that soil is the source of all mineral elements found in plants. Most naturally occurring deficiencies in livestock are associated with specific regions and are directly related to both soil mineral concentration and soil characteristics. Of the total mineral concentration in soils, only a fraction is taken up by plants.

Conrad (1978) indicates that grazing ruminants are in close and continuing contact with the soils on which the plants grow. Soils often contain many times the levels of minerals which are found in the plants which grow on these soils.

For Reid and Horvath (1980), the availability of minerals in soils depends upon their effective concentration in soil solution. Williams (1963) indicates that the soil content of an element would seem the most important limitation. However, availability factors including soil pH, texture, moisture content, and organic matter are probably more often the limiting factors rather than soil mineral content.

Sanchez (1976) says that the majority of the soils of the humid tropics is acid. Soil acidity problems are associated with pH levels lower than 5.5 and the presence of exchangeable aluminum in the soil. Percent aluminum saturation, calculated on the basis of effective cation exchange capacity, is a useful measure of soil acidity.

For Sanchez (1976), acid soil infertility is due to one or more of the following factors: aluminum toxicity, calcium or magnesium deficiency, and manganese toxicity. Aluminum toxicity is the most common cause of acid soil infertility. This toxicity can be corrected by liming to pH 5.5 to 6.0 to precipitate the exchangeable aluminum as aluminum hydroxide. Liming rates can be calculated on the basis of 1.65 ton/ha of $CaCO_3$ equivalent per milliequivalent of exchangeable aluminum. Overliming to pH values greater than 6 or 7 can seriously decrease yields, particularly in soils high in iron and aluminum oxides (Kamprath, 1972).

Concentrations of soil solution aluminum above 1 ppm often causes direct reduction in yield. Aluminum tends to

accumulate in the roots and impede the uptake and translocation of calcium and phosphorus. Thus aluminum toxicity may produce or accentuate calcium and phosphorus deficiencies (Foy, 1974).

Under grazing conditions, sheep and cattle can ingest large amounts of aluminus of nonplant origin when soil is involuntarily ingested with forages. Exchangeable aluminum concentrations of 6,000 and 18,000 ppm have been reported for samples of temperate and tropical soils, respectively (Velez and Blue, 1971).

Manganese is very soluble at pH values lower than 5.5. If present in sufficient amounts, manganese toxicity can occur along with aluminum toxicity at pH values of up to about 5.5 to 6.0. Manganese is a plant nutrient; consequently, the aim is not to eliminate soluble manganese but to keep it within a range between toxicity and deficiency. A solution concentration between 1 and 4 ppm represents such a range (Black, 1967).

Referring to organic matter, Sanchez (1976) indicates that in unfertilized soils the beneficial effects of organic matter consist of supplying most of the nitrogen and sulfur to plants, maintaining cation exchange capacity, blocking phosphorus fixation sites, improving structure in poorly aggregated soils, and the formation of complexes with micronutrients. For Dahnke and Vasey (1973), a test for total nitrogen and a test for organic matter or organic

carbon are essentially the same because the concentration of nitrogen in soil organic matter is relatively constant.

Soil Macronutrients

Towers and Clark (1983) indicated that mineral concentrations in both soil and plant influence the mineral status of grazing animals but many other factors such as total dry matter intake, selective grazing, interactions among minerals, variations in mineral requirements with differences in age, sex or production level also play an important part. This means that soil analysis alone cannot be used to reliably diagnose trace element deficiencies in animals.

A more satisfactory soil analysis to relate mineral concentrations for livestock rather than the concentration of a mineral in a soil, is the use of soil extracts (i.e., 0.1N HCl or 2.5% acetic acid), which contain the more available forms of soil minerals. Analyses to determine the available forms of soil micrals can sometimes provide evidence of livestock mineral deficiencies, but more often they are unreliable and difficult to interpret (McDowell et al., 1986).

Calcium is essential, not only to correct soil acidity but also as a nutrient element necessary for normal plant growth. Soil calcium plays an essential role in regulating soil pH (Gillanpas, 1982). The same author determined that the calcium concentration of soils are poorly reflected in the calcium concentration of plants.

Doll and Lucas (1973) stated that plants usually contain more potassium than any other nutrient element except nitrogen. Crops utilize from 50 to over 200 kg/ha, depending upon the yield and kind of crop. Supplemental potassium fertilizers are frequently needed since most soils can not meet the requirements of continued cropping. Levels of calcium in crops are lower than potassium, and the amount needed by crops usually is between 20 and 150 kg Ca/ha. However, nutrient deficiencies of calcium are not common since most soils either contain high levels of calcium or have been supplied with ample calcium because of liming. Uptake of magnesium by crops is relatively low, from less than 10 to about 25 kg/ha. Occasional magnesium deficiencies have been noted, especially on sandy soils or soils with low levels of magnesium in relation to potassium and possibly calcium.

Phosphorus is classed as one of the macronutrients, but its concentration in plants is considerably less than that of nitrogen, potassium and calcium. As a limiting factor, however, phosphorus is more important than calcium and probably more important than potassium. The forms of phosphorus that occur in soil parent materials are generally of low availability to plants. Probably all forms of phosphorus in soils are of some significance in supplying phosphorus for plants on a long-term basis, but none of the forms that have been identified are known to be of significance in the short-term relationships that are of

importance in determining the current availability of soil phosphorus (Black, 1968).

Sanchez (1976) stated that in general, sulfur deficient soils have one or more of the following properties. They are high in allophane or oxides. They are also low in organic matter and often sandy. Soils subject to repeated annual burning are often sulfur deficient since about 75% of the sulfur is volatilized by fire. In temperate regions total soil sulfur is positively correlated with organic matter and inversely correlated with degree of weathering. Sanchez (1976) also stated that sulfur deficiency in grazing sheep and cattle is not a problem, but its effect on copper absorption and metabolism is important.

Sodium is of importance in plant nutrition not only because sodium is required by at least a few plants, but also because of its relation to potassium. Sodium and potassium are the two principal monovalent metallic cations in plants, and an increase in one generally brings about a decrease in the other (Black, 1968). Table 1 provides a summary guide to the levels of soil fertility and its interpretation according to several authors.

Soil Micronutrients

Sulfur and the micronutrients can be differentiated from nitrogen, phosphorus, and potassium in that they are much less frequently the limiting factor in soil fertility (Foth and Ellis, 1988). Both copper and zinc occur in the earth's crust primarily as sulfide minerals. Deficiencies

TABLE 1. CONCENTRATIONS (PPM) OF MINERALS OF DRIED SOIL AND THEIR INTERPRETATION[a]

Element	Levels			Soil type	Reference
	Low	Medium	High		
Calcium	0-71	72-140	>141		b
Magnesium	0-30	30-50	> 60		c
Phosphorus	9-17	17-35	35-70	Organic-Mineral	c
Potassium	31-62	62-124	124-248	Organic-Mineral	c
Sulfur	<10	>10			d
Boron	< .4				e
Copper	< .1-.3			pH 5.5-6.0	e
Iron	< 2.5	> 4-5			f
Manganese	< 3-5			pH 5.5-6.0	e
Zinc	< .5			pH 5.5-6.0	e

[a]For grazing livestock soil concentrations suggesting deficiencies are as follows: calcium (70 ppm), potassium (58.5 ppm), magnesium (8.4 ppm), phosphorus (10 ppm), cobalt (0.1 ppm), copper (0.6 ppm), manganese (19 ppm), and zinc (2 ppm) (McDowell et al., 1986).

[b]Breland, 1970.

[c]Rhue and Kidder, 1983.

[d]Cooper, 1968.

[e]Gammon, 1976.

[f]Viets and Lindsay, 1973.

of copper are not commonly found in mineral soils. Organic soils containing little ash are more likely to be deficient. More than 99% of the copper in the soil solution is complexed by organic matter. This complexing is of great importance in maintaining adequate copper in solution for plant use. Organic matter does complex zinc in soil solution, but the percentage of zinc that is complexed varies over a considerable range (Foth and Ellis, 1988).

Since manganese solubility is related to oxidation-reduction reactions in the soil, the availability of manganese is closely related to weather. Cool temperatures may slow down the mineralization of organic manganese. On the other hand, cool temperatures associated with high levels of rainfall in early spring may keep more manganese available through reduction of manganese oxides. There is an interaction between manganese and iron. High levels of available iron in organic soils or high levels of organic matter in sands may lead to a manganese deficiency because a high ratio of iron to manganese is created within the plant (Foth and Ellis, 1988)

Foth and Ellis (1988) also state that few, if any, soils are deficient in total iron since the total soil iron concentration varies from 1,000 to 10,000 ppm. But the solubility of iron in soils may be limited by the low solubility of iron hydroxides and oxides in the pH range in which crops are grown. Soil conditions that lead to iron

deficiency in plants include pH above 7.0, low soil moisture concentration, and low organic matter concentration.

Boron is associated with soil organic matter, and soils with high levels of organic matter usually contain adequate boron for high soil fertility. Boron deficiency is often accentuated when soil contains little moisture.

As with other elements, the total concentration of selenium in soils shows little relationship to the concentration of selenium in plants grown on those soils. This is because selenium in soils exists in several chemical forms which differ widely in their solubility and availability to plants. The chemical forms of selenium (selenides, selenites, selenates, organic selenium) are closely related to oxidation-reduction potential and pH of the soil (Lakin, 1972).

Many studies have determined the factors effecting the availability of the microelements. The amount of most trace elements in herbage grown in freely drained soils is normally lower than on corresponding poorly drained soils (Swift, 1972).

As soil pH increases, the availability and uptake of iron, manganese, zinc, copper, and cobalt decrease, whereas molybdenum and selenium concentrations increase (Pfander, 1971; Williams, 1963; Lattaur, 1962; Miller et al., 1972). Many data have accumulated indicating a decrease in the solubility of zinc with increasing pH (Foth and Ellis, 1988).

Low soil temperatures usually decrease micronutrient availability and may cause deficiency signs to develop during cold springs only to disappear when the soil warms up and more roots develop (Viste and Lindsay, 1973).

Mineral Status of Plants

Of the thirteen essential minerals obtained from the soil by plants, five are used in relatively large quantities and are thus referred to as macronutrients. These are phosphorus, potassium, calcium, magnesium, and sulfur. The other minerals, iron, manganese, copper, zinc, boron, molybdenum, chlorine and cobalt, are used by higher plants in very small amounts, thereby giving them the designation of micronutrients or trace elements (Brady, 1974; McDowell et al., 1983).

Mineral analysis of the forage consumed by the grazing animal is basic to mineral status diagnosis. If mineral concentrations are below minimum requirements or above the maximum tolerance level, there is an immediate suggestion of a nutritional problem. However, relying on a forage mineral analysis to establish mineral status assumes that the sample is representative of what animals consume. An additional disadvantage of forage element analyses is the difficulty of estimating forage intake and digestibility (McDowell et al., 1986). Table 2 presents a guide to mineral element

TABLE 2. SUMMARY GUIDE TO MINERAL REQUIREMENTS FOR RUMINANTS (DRY BASIS)

Element	Requirement*
Calcium	.18-.60 %
Phosphorus	.18-.43 %
Magnesium	.04-.18 %
Potassium	.60-.80 %
Sodium	.10 %
Iron	10-100 ppm
Copper	4- 10 ppm
Cobalt	.05-.10 ppm
Zinc	10- 50 ppm
Manganese	20- 40 ppm
Molybdenum	.01 ppm or less

*Summarized by McDowell et al. (1978).

requirements for grazing ruminants, dry basis, summarized by McDowell et al. (1978).

Gross and Jung (1981) established that forages supply much of the minerals in diets fed to cattle, and that variation in the amount of minerals in forages are associated with season, fertilization, soil type, and soil pH.

Both amount of mineral in forages and biological availability of minerals need to be considered in formulating rations. Although mineral concentration of forages can be determined chemically, biological availability is much more difficult to estimate. Biological availability of mineral elements in forages is probably a partial function of the extent to which they are solubilized in rumen fluid (Kincaid and Cronrath, 1983).

Grazing livestock usually do not receive mineral supplementation except for common salt and must depend almost exclusively upon forages to meet their requirements. Only rarely, however, can forages completely satisfy all mineral requirements (McDowell et al., 1982).

Forage Macrominerals

Phosphorus deficiency is found frequently in tropical grazing areas around the world (Cohen, 1980), and may be the first limiting mineral deficiency under many grazing conditions. Aluminum and iron in ingested soil may interfere with dietary phosphorus utilization (Rosa et al.,

1982) and this effect could be critical if the animals were in a borderline phosphorus deficiency. The phosphorus requirement of a ruminant is rarely met by forage diets; therefore, supplementation is then necessary (Cohen, 1980).

Calcium deficiency is a lesser problem than phosphorus deficiency in grazing animals because most herbage contains adequate calcium, and maturity has only a small effect on calcium concentration. In contrast, most of the world's rangeland soils are low in phosphorus and support herbage of low phosphorus concentration which declines markedly with maturity (Underwood, 1981).

Magnesium occurs widely in plant and animal tissues. Magnesium content of most grazed herbages usually exceed 0.1% so requirements for supplemental magnesium in grazing cattle and sheep are usually associated with induced hypomagnesemia as a result of higher concentrations of nitrogen and potassium due to fertilization rather than low magnesium levels per se (Cohen, 1987). Metson et al. (1966) suggested that magnesium levels of 0.25% were necessary to prevent grass tetany when concentrations of nitrogen and potassium are high.

Potassium is often associated with high levels of nitrogen and moisture in lush, cool-season grasses (Boling et al., 1979). Ruminants grazing pasture heavily fertilized with potassium have developed hypomagnesemic tetany, but adding potassium salts directly to their diet usually failed to produce this condition (Tomas and Potter, 1976).

Excess sodium salts in the diet may increase the rate of passage of digesta and, thus, enable a greater quantity of dietary protein to escape ruminal degradation (Reffett and Boling, 1985). Moseley and Jones (1974) reported that feeding high levels of NaCl resulted in increased magnesium absorption, but concomitantly resulted in increased urinary excretion of sodium and magnesium.

Forage Microminerals

An accurate determination of zinc requirements of ruminants is not available, although the level of 25 to 30 ppm in forage is consistant with results obtained from grazing experiments. Zinc concentrations may be 30 ppm in herbage and occasionaly higher, but this concentration declines rapidly as plants mature and values can decrease to less than 15 ppm (Mayland et al., 1987). The bioavailability of zinc may be reduced by cellulosic binding (Kramer and Knight, 1970).

Forage copper concentrations vary from 4 to 5 ppm to values of 10 to 15 ppm. Sulfur and molybdenum interfere with the absorption of copper. Variations in copper absorption may more often be associated with changes in soil pH or redox potential that have effected the solubility and uptake of molybdenum and/or sulfur (Langlands et al., 1981; Lesperance et al., 1985).

Absorption of copper varies according to age and dietary factors such as the level of molybdenum and sulfur. Zinc and calcium levels in the diet may also interact with

copper absorption, but to a lesser extent than do molybdenum and sulfur. Herbage containing 5-6 and 7-10 ppm of copper should meet the copper requirement of sheep and cattle, respectively, unless amounts of molybdenum and sulfur intake are high. A copper:molybdenum ratio of 2.0 or greater is desirable to avoid molybdenosis (Miltmore and Mason, 1971; Ward, 1978).

A deficiency of copper in cattle occurs when the dietary level is much less than 5 ppm DM or when molybdenum or sulfur are in excess (Ward, 1978). Ward (1978) reported that dietary copper:molybdenum ratios less than 2:1 contribute to a copper deficiency, whereas an excess of dietary sulfur potentiates the effect of molybdenum.

Cobalt is the metal cofactor in vitamin B_{12} which is in turn required in energy metabolism in ruminants (Mayland et al., 1987). Pasture herbage levels of at least 0.08 and 0.11 ppm will provide adequate cobalt for cattle and sheep, respectively (Grace, 1983). Ruminants on Phalaris pastures can develop an acute form of a disease from which they quickly die or a chronic form of a nervous disorders characterized by muscle tremors, rapid breathing and pounding heart beat. Phalaris staggers is the name given to this disorder. Grazing Phalaris increases the cobalt requirement (Mayland et al., 1987).

The toxicity and metabolism of molybdenum are dependent not only on the levels of dietary molybdenum but also on the levels of other dietary components. The higher the level

of molybdenum, the greater the amount of copper required to prevent signs of molybdenosis. Prolonged high molybdenum intakes cause hypocupremia (Underwood, 1981).

Molybdenum-induced copper deficiency is an endemic problem in ruminants (Ward, 1978). Dietary levels of molybdenum are effected by parent soil material, soil pH, forage type and forage maturity (Reid and Horvath, 1980). Molybdenum combines with hydrogen sulfide in the rumen to form thiomolybdates which render copper unavailable for absorption (Dick et al., 1975).

In many areas sheep and cattle grow normally on pastures containing 0.03 ppm of selenium and show no evidence of a deficiency. In other areas, white muscle disease can occur, especially in lambs, where pastures contain as much as 0.05 ppm. These responses may be attributed to variations in dietary sulfur levels or other factors that affect the absorption of selenium or the requirement of selenium by the animal. The requirement for selenium in sheep is given by the National Research Council (NRC, 1985) as 0.1-0.2 ppm. A value of 0.1 is often used as a critical level, but this should be evaluated on a basis of animal performance (Mayland et al., 1987). Selenium deficiency is associated with pastures that contain less than 0.03 ppm (Miller, 1983).

Mineral Status and Requirements of Ruminants

Table 3 presents the requirements and critical levels for the diagnosis of specific mineral deficiencies or toxicities in sheep. Without question, forage analysis is a much better indicator of mineral status for ruminants than is soil analysis. Likewise, animal tissue-mineral concentrations are better indicators of the availability of minerals than are forage mineral analyses. Grazing livestock obtain part of their mineral supply from the consumption of water, soil, leaves, tree bark, etc, rather than entirely from forages (McDowell et al., 1986).

Evaluating the mineral status of domestic animals can be a complex and costly procedure. Often little is known about the nutritional background of animals in question. Collecting blood or tissue samples for mineral analysis is often impractical because of limited facilities and personnel trained to collect samples (Combs, 1987).

Tissue Macrominerals

Calcium is the most abundant of the minerals in the animal body. About 26-30% of total ash content of most animals is calcium. Although about 98-99% of the total body calcium is in the skeleton, it has numerous crucial functions in soft tissues. The active form of calcium in soft tissues is the ionized form. Ionized calcium content of blood plasma is homeostatically regulated within

TABLE 3. DIAGNOSIS OF SPECIFIC MINERAL DEFICIENCIES OR TOXICITIES IN SHEEP

Element	Dietary requirement (dry basis)[a]	Tissue	Critical level[b,c]
Deficiency			
Calcium	.20-.82 %	Bone (fat free)	24.5 %
		Bone ash	37.6 %
		Plasma	8 mg/dl
Phosphorus	.16-.38 %	Bone (fat free)	11.5 %
		Bone ash	17.6 %
		Plasma	4.5 mg/dl
Magnesium	.12-.18 %	Serum	1-2 mg/dl
		Urine	2-10 mg/dl
Potassium	.50-.80 %		
Sodium	.09-.18 %	Saliva	100-200 mg/dl
Sulfur	.14-.26 %		
Iodine	.10-.80 %	Milk	300 ug/day
Iron	30-50 ppm	Hemoglobin	10 g/dl
		Transferrin	13-15 % saturation
Copper	7-11 ppm	Liver	25-75 ppm
		Serum	.65 ug/ml
Molybdenum	.5 ppm		
Cobalt	.1-.2 ppm	Liver	.05-.07 ppm
Manganese	20-40 ppm	Liver	6 ppm
Selenium	.1-.2 ppm	Liver	.25 ppm
		Serum	.03 ug/ml
		Hair or wool	.25 ppm

TABLE 3.--CONTINUED

Element	Dietary requirement (dry basis)[a]	Tissue	Critical level[b,c]
Toxicity			
Copper	25 ppm	Liver	700 ppm
Fluorine	60-150 ppm	Bone	4500-5500 ppm
Manganese	1000 ppm	Hair	70 ppm
Iron	500 ppm		
Molybdenum	10 ppm	Liver	4 ppm
Selenium	>2 ppm	Liver Hair	5-15 ppm 10 ppm
Zinc	750 ppm	Hair	10 ppm

[a]NRC (1985). Requirements below which a deficiency occurs.

[b]References for critical levels are found in the following reviews: Mtimuni (1992), McDowell et al. (1984).

[c]Non-mineral assays for the following elements are sensitive diagnostic techniques: cobalt (Vitamin B_{12}), iodine (free thyroxine), copper (ceruloplasmin) and selenium (glutathione peroxidase).

relatively narrow limits. The skeletal system serves as a very effective reservoir of calcium, which maintains ionized plasma calcium levels within narrow limits under a wide range of dietary calcium intakes (Combs, 1987).

Calcium, phosphorus and magnesium are important components of bone, and also intracellular and extracellular fluids of the body. Extracellular calcium is essential for maintenance of nerve tissue, resting membrane potential, blood clotting mechanisms, myocardial contraction and myoneural junctional transmission. Intracellular calcium, directly or indirectly, regulates activity of many enzymes, microtubule assembly, generation of ATP, release of hormones and neurotransmitters and muscle cell contraction (Littledike and Goff, 1987). Excess calcium may impair reproductive function by causing a secondary deficiency of phosphorus, magnesium, zinc, copper and other micronutrients by inhibiting their absorption in the intestine (King, 1971).

Phosphorus has long been recognized as a major essential nutrient for ruminants. Approximately 80% of body phosphorus occurs in bone and skeletal development depends upon an adequate supply of phosphorus. Phosphorus is required for phosphorylation in sugar metabolism, intracellular energy transfer, formation of phospholipids, as a buffer in blood and other fluids and is required for proper functioning of rumen microorganisms (Cohen, 1987).

Phosphorus is also abundant in animal tissues, accounting for 16-17% of total body ash.

Severe deficiencies of phosphorus in cattle reduce feed intakes, feed efficiencies, and retard growth (Kincaid et al., 1981). The requirement for phosphorus as a percent of dry matter in rations for sheep is given by the National Research Council (NRC, 1985) as 0.16-0.38%.

Dietary calcium:phosphorus ratios may effect reproductive performance. Phosphorus deficiency induces lowered conception rate, irregular estrus, decreased ovarian activity, increased incidence of cystic follicles, and generally depressed fertility. When phosphorus levels are low, phosphorus supplementation, while expensive, is critical to animal performance (Hurley and Doane, 1989).

There has been increasing acceptance of the rib bone biopsy technique (Little, 1972) as a more reliable method for the estimation of phosphorus status of grazing cattle and sheep than blood. McDowell (1985) has indicated that this technique is being used widely as a survey technique to locate mineral deficiencies in tropical regions.

About 70% of total body magnesium in livestock occurs in the bones. It also occurs in high concentrations in intracellular fluid where it is associated with the mitochondria and in lesser concentrations in the extracellular fluid. It is involved in oxidative phosphorylation, phosphate transfer, metabolism of carbohydrates and lipids and in neuromuscular activity

(Cohan, 1987). Magnesium accounts for 1-1.1% of total ash of most animal species and is deposited primarily in skeletal and muscle tissue. Seven to eight % of the total body stores of magnesium is in other tissues and body fluids (Combs, 1987).

Magnesium is an essential cofactor of many enzymes, especially phosphate-transferring enzymes involved in ATP generation and the adenylate and guanate cyclases, and is essential for normal function of nerve tissues (Littledike and Goff, 1987).

The magnesium status of livestock can be assessed from plasma, whole blood or urine (Egan, 1980). Normal magnesium levels in plasma of sheep are listed as 1.8-2.0 mg/dl with values below 1.0 mg being severely hypomagnesemic (NRC, 1985). The National Research Council (1985) suggested minimum magnesium requirements of 0.12, 0.15 and 0.18% of dry matter for growing lambs, for ewes in late pregnancy, and for ewes in early lactation, respectively. Studies have shown that excess magnesium intake by ruminants caused loss in weight, drowsiness and changes in blood mineral levels (Gentry et al., 1978).

Hypomagnesemic tetany is a problem in ruminants managed under a variety of regimens. The disorder has been reported in milk-fed calves, and in adult sheep and cattle fed high-roughage diets or maintained on sparse pasture (Giduck and Fontenot, 1987). A deficiency of magnesium in ruminants may result from low magnesium concentrations in feeds or a

reduction in biological availability of dietary magnesium (Fontenot, 1982).

Sodium, potassium and chlorine function in maintaining acid-base balance, osmotic pressure and body fluid balance. Sodium is involved in transmission of nervous impulses and occurs largely in the body fluids and bones while potassium occurs mainly in the muscle, nervous tissue and erythrocytes (Cohen, 1987).

Sodium deficiency leads to a pica or craving for salt, unthrifty appearance, loss of appetite, weight loss and reduced milk yield. These signs usually occur without a decline in plasma sodium, although urinary and fecal sodium may decline (Underwood, 1981). The National Academy of Sciences (NRC, 1985) listed sodium requirements at 0.09-0.18% dry matter of the diet and potassium at 0.50-0.80% dry matter.

Tissue Microminerals

Zinc occurs widely and in relatively high concentrations throughout the body. Zinc concentrations in plasma of sheep and cattle range from 0.6 to 1.2 ppm, respectively. Zinc is a constituent of a large number of metallo-enzymes involved in biochemical processes essential to nucleic acid and carbohydrate metabolism, as well as protein synthesis. It is associated with appetite, growth, male sexual development and wound healing. There are no significant stores of body zinc, and the animal must rely on a daily supply to meet requirements (Mayland et al., 1987).

Largely on the basis of Australian studies, Underwood (1981) concluded that zinc requirements for optimum growth and fertility of sheep must lie close to 30 ppm of the dry diet. The NRC (1985) requirements of sheep are given as 29 to 33 ppm.

Clinical signs of severe zinc deficiency have been reported in ruminants under practical conditions. However, a marginal zinc deficiency appears to be a more widespread occurrence (Spears, 1989). Low zinc intake throughout pregnancy has severe effects on reproduction in the ewe. Because signs of zinc deficiency are nonspecific, poor zinc status should be considered in cases of unexplained reproductive problems (Apgar and Fitzgerald, 1985). Excess dietary iron can affect performance adversely in ruminants. High dietary iron can affect utilization of other minerals such as copper, phosphorus, zinc and manganese (Humphries et al., 1983).

The liver is the primary storage organ of body copper stores, having about 40-70% of the total copper. Copper is active in the conversion of tyrosine to melanin, which provides the color pigment in hair and wool. About 20% of the plasma copper is in a loosely bound form, while the other 80% is associated with a protein called ferroxidase I (Ceruloplasmin). Ferroxidase I oxidizes ferrous iron (Fe^{2+}) to ferric (Fe^{3+}) allowing the mobilization of iron stores (Meyland et al., 1987).

Adequate maternal intake of copper is essential for development of the central nervous system of the embryonic lamb. Enzootic ataxia of the unborn or the unweaned lamb is primarily from copper deficiency (Hidirogleu and Knipfel, 1981). Visible signs of copper deficiency are not usually seen in the adult sheep. Copper deficient lambs may have a degenerative disorder known as swayback (Poole, 1982).

Physiological copper deficiencies are produced by four classes of feeds: (1) high molybdenum, generally above 100 ppm, (2) low copper:molybdenum ratio, 2:1 or less, (3) copper deficiency, below 5 ppm, and (4) high protein, 29-30% protein in fresh forage (Ward, 1978).

Copper toxicity is essentially a problem of the housed ruminant because housed ruminants are given foodstuffs of high copper availability. Conversely, copper deficiency is a problem of the grazing animal because of the poor availability of copper in grass, so low as to be less than 10% of that found in some foodstuffs (Suttle, 1985).

Sulfur in the inorganic form, which is converted within the gastrointestinal tract to certain amino acids and B-vitamins by rumen microorganisms, can meet the needs of ruminants for sulfur. This process provides methionine, thiamin and biotin, which otherwise would need to be provided by the diet to meet the needs of sulfur-containing compounds for the animal's metabolic, regulatory and structural functions. All other sulfur-containing compounds

required by mammalian tissue can be synthesized from methionine (Goodrich and Thompson, 1981).

Elevated molybdenum intakes depress copper availability and may produce a physiological copper deficiency in ruminants. Total sulfur or sulfate in the ration generally potentiates the effect of molybdenum. The ratio of copper to molybdenum in feed is important regardless of the absolute amount of each. For this reason, and because of the importance of the sulfur content of the diet, it is impossible to define safe dietary limits of copper and molybdenum (Ward, 1978).

Thiomolybdates reduce the absorption of dietary copper in sheep. They also affect systemic copper metabolism by changing markedly the distribution of copper in plasma and by reducing the availability of copper to metabolic sites within the body (Gooneratne et al., 1989).

According to Meyland et al. (1987) loss of appetite, high aspartic aminotransferase, and low blood plasma glucose levels are the best indicators of cobalt deficiency. Serum vitamin B_{12} less than 0.20 ng/ml will also indicate a possible cobalt deficiency, but liver cobalt levels are not always reliable estimates of cobalt status.

Selenium is widely distributed in the body. The kidney and liver normally have the highest concentrations. Selenium is an integral part of the enzyme glutathione peroxidase which catalyzes the reduction of peroxides, thereby protecting tissues against oxidative damage.

A dietary concentration of 0.1-0.2 ppm of selenium has been accepted by the NRC (1985) as a safe and adequate level for the prevention of white muscle disease in sheep. Workers in New Zealand found that lambs grew normally with no signs of white muscle disease when pastures contained 0.03 to 0.04 ppm of selenium (Hartley and Grant, 1961). However, Whanger et al. (1978) reported white muscle disease in lambs fed diets containing 0.1 ppm of selenium.

High levels of oral copper have been reported to reduce selenium availability in nonruminants. Copper often is added to mineral mixes for ruminants, and copper toxicosis is relatively common in sheep (Underwood, 1981). White et al. (1989) showed that copper or molybdenum supplements at 10 mg/kg to practical-type diets of ewes and lambs had no effect on selenium status.

Hematological Measurements

Blood is the principal fluid transport system in the body and provides an expedient source of metabolic products. Chemical analysis of serum and plasma provide quantitative estimates of physiological parameters for diagnosis of disease. Quantitative differences among normal cows have been found for many of these variables by Peterson et al. (1982).

Hemoglobin is the oxygen-carrying compound contained in red blood cells (RBC). The amount of hemoglobin per 100 ml

of blood can be used as an index of the oxygen-carrying capacity of the blood. Total blood depends primarily on the number of RBCs (the hemoglobin carriers) but also, to a much lesser extent, on the amount of hemoglobin in each RBC (Ravel, 1989). Reference values are most frequently quoted in sheep as 9-15 g/dl (Table 4).

Since whole blood is made up essentially of RBC and plasma, the percentage of packed RBCs after centrifugation gives an indirect estimate of the number of RBCs/100 ml of whole blood. Hematocrit thus depends mostly on the number of RBCs, but there is some effect (to a much lesser extent) from the average size of the RBC (Ravel, 1989).

White blood cells (WBC or leucocytes) form the first line of defense of the body against invading microorganisms. Neutrophils and monocytes respond to phagocitosis; lymphocites and plasma cells apparently produce antibodies (Ravel, 1989).

TABLE 4 NORMAL BLOOD HEMOGLOBIN, HEMATOCRIT AND LEUCOCYTE VALUES FOR THE SHEEP

	Range[a]	Average
Hemoglobin, g/dl	9-15	11.5
Hematocrit, %	27-45	35
Leucocytes, /ul	4000-12,000	8000
Neutrophil (mature), %	10-50	30
Lymphocyte, %	40-75	62
Monocyte, %	0- 6	2.5
Eosinophil, %	0-10	5
Basophil, %	0- 3	0.5

[a]Schalm and Nemi (1986).

CHAPTER III
MATERIALS AND METHODS

Identification and Description of Research

The research for the present study was conducted at three sheep farms located in the paramo region of the Cordillera Oriental of Colombia during both the rainy and dry seasons.

San Jorge farm belongs to Instituto Colombiano Agropecuaria (ICA) and is located in Soacha (Cundinamarca), on one dry area of the paramo. Don Benito and San Francisco farms belong to Caja de Credito Agrario Industrial y Minero (Caja Agraria) and are located in Zipaquira (Cundinamarca) and Ventaquemada (Boyaca), respectively, on wet areas of the paramo (Appendix B, table 20). About 36% of the total sheep population, or 85% of the wooled sheep of the Country are located in these two departments (Cundinamarca and Boyaca). Location of the farms is shown in Appendix A, figure 2.

Soil, forage and animal tissue samples were collected from the three farms during the rainy and dry seasons. The two seasons were selected based on the pattern of rainfall There are two relatively short but marked rainy seasons during the year from mid-April to mid-June and then from

mid-September to mid-November. Appendix 8 table 20 shows the climate and average monthly rainfall of two of the farms. The first sampling period corresponded to the end of the rainy season (May, June 1987) and the second sampling corresponded to the middle-end of the dry season (February 1988).

Identification and a general description of parameters in evaluating animal production for each farm appears in appendix B table 19. This information was provided by farm managers during the sample collection period in 1988. Some data were derived from an approximation by the manager in cases where exact information was not available.

Sample Collection

Soil Samples

A total of 113 composite samples were collected from the three farms during both 1987 and 1988 sampling periods. Each composite sample was made up of 8-12 samples taken from predetermined areas of a paddock, totalling 4-5 composite samples from each paddock

Twenty, nineteen and twenty composite samples from different paddocks were collected from San Jorge, Don Benito and San Francisco, respectively, during 1987 (rainy season) sampling period. Twenty, fourteen and twenty composite

samples from different paddocks were collected from San Jorge, Don Benito and San Francisco, respectively, during 1988 (dry season) sampling period.

Samples of soil were taken from the top layer (20 cm) using a stainless steel bore. A soil sampling technique described by Bahia (1978) was used. Although soil samples collected during the two seasons did not come from the exact same spot, they came from the same grazing area of the farm.

Based on texture, the soil of the upper part (above 3,000 m) of San Jorge is classified as loamy (about 50%) or silt loam (about 50%); in the lower part (below 3,000 m), about 40% of the soil is clay, 40% is clay loam and sandy clay loam, and the rest is sandy clay, loam, and sandy loam. In Don Benito the predominant soil is loamy, and in San Francisco it is either loamy or silt loam.

Proper identification of each paddock is in appendix C, and the detailed number of composite soil samples is in appendix E table 21.

Soil and forage samples were collected one or two days before animal tissue samples were taken. Approximately 500 g composite soil were transferred to plastic bags and were properly identified for further analysis at the Soils Laboratory at Tibaitata, ICA, Colombia. Twenty gram subsamples were taken, transferred to small plastic bags and were properly identified for selenium analysis in the United States.

Forage Samples

A total of 131 composite forage samples were taken from the three farms during both the rainy season (1987) and the dry season (1988). Twenty-eight, twenty and nineteen composite samples containing the major species of forage from San Jorge, Don Benito and San Francisco, respectively, were taken during the 1987 (rainy) collection period. Twenty-nine, fifteen and twenty composites from San Jorge, Don Benito and San Francisco were taken during the 1988 (dry) collection period. The forage species collected were: vernalgrass (Anthoxanthum odoratum), a native cultivar of velvetgrass (Holcus lanatus L), an imported cultivar of velvetgrass (H. lanatus basyn), kikuyugrass (Pennisetum clandestinum), white clover (Trifolium repens), tall fescue (Festuca arundinacea), and orchardgrass (Dactylis glomerata).

In both collections forage samples were taken from the same areas where soil samples were taken. Appendix B table 21 shows the detailed number of forage samples; proper identification of paddocks and of forage species is in appendix C.

Each of the farms maintains about 3 sheep/ha/year under a rotational grazing system (appendix B table 19). There is not a fertilization program in San Jorge; however, some paddocks in the lower part of the farm receive nitrogen (in the form of Urea) which is applied at 50 kg ha^{-1}. In Don Benito and San Francisco pastures are not fertilized;

however, some paddocks take advantage of residual fertilization as a consequence of potato cropping.

Each of the composite forage samples from each paddock came from 20-25 individual samples of the same forage species predominating and most frequently grazed by sheep on the different areas of the fars

To avoid contamination, plastic gloves were utilized for forage collection. Only the aerial part of the forage (about 5 cm from the ground) was taken. Samples were collected in plastic bags and kept refrigerated at 5° C until further processing. Samples were then hand separated by species and within each species samples were further separated into two parts, stems and leaves. A third component of the sample was left totally unseparated and analyzed separately as "whole plant", but no comparisons were made with the stem and leaf components of the same plant. Plant parts were transferred to paper bags and oven dried at 60° C for 48 hours. After this process, the samples were ground in a hammer mill with stainless steel knives and 1 mm screen at ICA facilities in Bogota. After mixing, a 60 g sample was transferred into a plastic bag and properly identified for further chemical analysis in the Nutrition Laboratory of the University of Florida.

Animal Tissue Samples

Blood serum, whole blood, bone and liver samples were collected from sheep on each farm. The animals were divided

into three classes: lactating (or pregnant) ewes, lambs (1-4 months of age) and yearlings (10-14 months of age).

Because of timing differences in the breeding seasons, it was not possible to collect samples from lambs in San Francisco at the 1987 collection period because they were very young or not yet born; in this case their mothers were in their last trimester of pregnancy. Appendix B table 23 details the number of animal tissue (serum, whole blood, liver, and bone) samples taken.

The animals in San Jorge were Criollo x Romney or Criollo x Corriedale crosses and in Don Benito and San Francisco the animals were Criollo x Blackface crosses (appendix B table 19).

During each sampling period, animals from the desired classes were selected at random from each farm. Because it was not possible to follow the animals sampled during the rainy season of 1987, other animals were randomly selected in the dry season of 1988. Animal stress and excitement were minimized during and prior to tissue sample collection.

The composition of the mineral mixture given on the three farms is presented in appendix B table 22. A majority of the animals received mineral supplementation although this was not done for the entire year especially in San Jorge farm.

Whole blood and blood serum. Duplicate blood samples were obtained by jugular puncture and were collected in monovette tubes (Sarstedt, West Germany). One of them

contained the anticoagulant NH_4-heparin. This tube was inverted 5 times so the blood made contact with the anticoagulant but avoiding hemolysis of the red cells. The blood samples were left standing in a cool environment and sent to Laboratorio de Investigaciones Medico Veterinarias (LIMV) in Bogota (ICA, Colombia) for the determination of hematocrit, hemoglobin and total and differential leucocyte counts.

The second tube was used for serum separation. The blood samples were centrifuged at 2500 rpm for 30 minutes at the respective farm. The serum samples were identified and kept frozen after centrifugation until the precipitation of serum proteins was completed at the University of Florida. Procedures and techniques for blood processing have been described by Fick et al. (1979). In total, 207 serum and 192 whole blood samples were analyzed.

Bone biopsy. A total of 148 bone biopsy samples were taken from the sheep. Bone biopsy samples were taken as described by Little (1972), with some modifications of the technique. A single sample was removed from the 12th rib on the right side of the animal. The procedure performed using the same vertical incision, approximately 4 cm in length made for the liver biopsy, was used for the bone biopsy. The width of the rib in sheep is so narrow that the biopsy was taken without using a trephine; instead, a piece of bone approximately 2 cm in length was removed by cutting a section of rib using a small stainless steel bone shear.

Bone samples were kept in individual plastic bottles containing 10% formalin for analysis at the University of Florida.

Liver biopsy. A total of 113 liver biopsy samples were taken from the sheep. Samples were taken in vivo using the technique described by Fick et al. (1979) and McDowell et al. (1983).

The same animals on each farm selected for blood sampling were used for liver biopsy sampling. Liver samples were kept frozen in 10% formalin for further analysis at the University of Florida.

Chemical Analysis

Soil Samples

Soil samples were analyzed by standard methods in the Laboratorio Nacional de Suelos in Tibaitata, ICA, Bogota for organic matter (OM), pH, aluminum, boron, calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc.

Aluminum (exchangeable acidity) was extracted from the soil samples with the solvent KCl, 1N; exchangeable basis were extracted with ammonium acetate and organic matter was determined by the Walkley and Black colorimetric method (Black, 1967). Phosphorus was measured using the method of Bray II (Jackson, 1958).

Soil mineral concentrations were determined by atomic absorption spectrophotometry (Perkin-Elmer, 1980). Selenium was analyzed at the University of Florida, by a fluorometric method (Whattar and Ullrey, 1979).

Forage Samples

Forage samples were processed and analyzed for mineral concentration according to methods described by Fick et al. (1979) at the Nutrition Laboratory, University of Florida. Calcium, copper, iron, magnesium, manganese, potassium, sodium and zinc were analyzed by atomic absorption spectrophotometry in a Perkin-Elmer AAS 5000 (Perkin-Elmer, 1980). Cobalt and molybdenum were analyzed by flameless atomic absorption spectrophotometry using a Perkin-Elmer AAS Zeeman/3030 (Perkin-Elmer, 1984). Phosphorus was determined by the colorimetric method described by Harris and Popat (1954) and included by Fick et al. (1979) as a method for phosphorus determination for plant and animal tissues. Selenium in forage samples was analyzed by a fluorometric method (Whettar and Ullrey, 1979).

For nitrogen analysis, samples were digested using a modification of the aluminum block digestion procedure of Gallaher et al. (1975). Sample weight was 0.3 g, catalyst used was 3.2 g of 9:1 K_2SO_4 : $CuSO_4$, and digestion was conducted for 4 h at 400° C using 10 ml H_2SO_4 and 2 ml H_2O_2. Ammonia in the digestate was determined by semiautomated colorimetry (Hambleton, 1977) Multiplication of nitrogen by 6.25 was the procedure for calculating crude protein. In

vitro organic matter digestion (IVOMD) was performed by a modification of the two-stage technique (Moore and Mott, 1974). Dry matter was determined by drying for 15 h at 105° C and organic matter by ashing for 15 h at 550° C.

Animal Tissue Samples

Blood serum. Serum brought to the University of Florida was deproteinized with 10% trichloroacetic acid (TCA) and then analyzed for mineral content according to the method described by Fick et al. (1979). Calcium, copper, magnesium, and zinc were analyzed by atomic absorption spectrophotometry using a Perkin-Elmer AAS 5000 (Perkin-Elmer, 1980). Phosphorus was determined by a colorimetric technique (Harris and Popat, 1954). Selenium was analyzed using the method of Whetter and Ullrey (1978).

Whole blood. Blood samples which contained anticoagulant were used to determine hematocrit, hemoglobin, and total and differential leucocyte counts in Laboratorio de Investigaciones Medico Veterinarias (LIMV), ICA, Colombia. The microhematocrit method was utilized using capillary tubes of 1.1-1.2 mm diameter in an International centrifuge with standardized reading scales. Centrifugation was for 5 minutes at 2500 rpm. After centrifugation, the height of the RBC column was measured and compared with the height of the column of original whole blood. The percentage of RBC mass to original blood volume is the hematocrit (Naval, 1989).

The hemoglobin concentration was obtained utilizing the oxyhemoglobin method. A .025 ml aliquot of blood is added to a test tube containing 5 ml sodium bicarbonate (.1% solution) and mixed (Schalm and Nemi, 1986). A Leitz spectrophotometer was utilized.

To determine total leucocyte counts, a Coulter Counter model FN (Coulter Electronics, Inc, Hialeah, Florida) was used. The Coulter Counter is based on the principle that cells are poor electrical conductors. A measured volume of diluted suspension of cells (in an electrically conductive medium) is drawn through a minute aperture between two electrodes. Each cell passing through the aperture displaces an equal volume of the electrolyte solution and is counted electronically and displayed on the digital readout (Schalm and Nemi, 1986). Differential leucocyte counts were appraised visually from prepared slides of blood smears using the methods described by Schalm and Nemi (1986).

Bone samples. The samples were dried and extracted in ether following procedures outlined by Fick et al. (1979) and subsequently analyzed for calcium, magnesium, and phosphorus.

Liver samples. Liver biopsy sample preparation was carried out as described by Fick et al. (1979). Dry tissue samples (approximately .3 g) were pre-ashed on a hot plate with 50% (v/v) nitric acid and then ashed overnight in a muffle furnace at increments of 100° C every hour until reaching 550° C. Ash was solubilized first with 50% nitric

acid, then with 10% nitric acid and finally, with distilled water. Solutions were filtered, diluted to appropiate range and analyzed with atomic absorption spectrophotometry for copper, iron, manganese, and zinc using a Perkin- Elmer AAS 5000 (Perkin-Elmer, 1980). Liver cobalt and molybdenum were determined by flameless atomic absorption spectrophotometry using a Perkin-Elmer AAS Zeeman/3030 (Perkin-Elmer, 1984). Selenium analysis was carried out by the technique of Whetter and Ullrey (1978).

Statistical Analysis

Data were analyzed by use of the Statistical Analysis System (SAS Institute., 1985). Probability level for significance was .05 in all statistical analyses.

Blood Serum, Whole Blood, Bone and Liver

Serum, whole blood, bone and liver were analyzed as a split-plot design with animal class as the main plot and season as the subplot. The model was as follows:

$$Y_{ijk} = u + A_i + B_j + C_{ij} + D_k + F_{ki} + G_{kj} + E_{ijk}\ , \text{ where,}$$

u = overall mean.

A_i = random effect of the ith farm.

B_j = effect of the jth animal class.

Cij = effect of farm*animal class (experimental error for animal class).

D_k = effect of the kth season.

F_{ki} = effect of season*farm.

G_{kl} = effect of season*animal class.

E_{ijk} = residual error (experimental error associated with the subplot).

Since the data were unbalanced, hypothesis testing was based on the Type IV Sum of Squares.

Soil and Forage

Soil and forage were analyzed as a split-plot design, with farm as the main plot and season as the subplot. For forage, plant part was considered as the subplot. The model was as follows:

$$Y_{ijk} = u + A_i + B_{j(i)} + C_k + D_{ik} + E_{ijk}$$, where:

u = overall mean.

A_i = fixed effect of ith farm.

$B_{j(i)}$ = effect of jth paddock within i^{th} farm (experimental error for farm).

C_k = effect of kth season. (k^{th} plant part, in forages).

D_{ik} = effect of farm*season (farm*plant part, in forages).

E_{ijk} = experimental error associated with subplots.

Correlation coefficients between soil and forage, forage and animal tissues, and serum, liver and bone responses were estimated. These estimates were obtained for each farm and class separately for the rainy and dry seasons.

Only those correlation coefficients of biological importance are discussed in the corresponding chapters.

CHAPTER IV
MINERAL STATUS OF SHEEP IN THE PARAMO REGION OF COLOMBIA I. MACROELEMENTS

Introduction

Sheep are adapted to the cold and harsh environment of the Colombian paramo; but it is commonly accepted that the few forage species that are grown are of low quality and their regrowth is very slow after grazing. Under these conditions animals do not get their nutritional requirements and, therefore, the sheep enterprise is not very efficient. Poor growth rate of lambs, low fertility in particular of imported breeds, high mortality and low wool production of inferior quality are characteristics of sheep production in the Colombian paramo (Proyecto Ovino Colombo Britanico, 1979).

Mineral deficiencies, imbalances, and toxicities have been reported to severely inhibit tropical cattle production systems (McDowell, 1985). It has been demonstrated that, with the exception of calcium and sulfur, none of the macroelements have adequate concentrations in some forage species grazed by sheep on the paramo (Laredo et al., 1989). The objectives of this study were to evaluate the macromineral status of grazing sheep and to determine macroelement status and other soil, forage, and blood

parameters in three farms as related to the wet and dry seasons of the Colombian paramo.

Materials and Methods

Soil, forage, and animal tissue samples were collected from three sheep farms in the paramo of the Cordillera Oriental of Colombia. Sampling periods corresponded to the end of the rainy season (May-June, 1987) and the middle to end of the dry season (February, 1988).

A total of 113 composite soil, 131 composite forage, 207 serum, 192 whole blood, and 148 rib bone biopsy samples were obtained for each of the sampling periods.

Each composite soil sample came from 8-12 samples. A soil sampling technique described by Bahia (1978) was used. Soil samples were analyzed by standard methods in the Laboratorio Nacional de Suelos of ICA in Bogota for organic matter, pH, aluminum, calcium, magnesium, phosphorus, potassium and sodium. Minerals were extracted from the soil samples with an acid extracting solution (.025N H_2SO_4 and .05N HCl).

Based on texture, the soil of the upper part (above 3,000 m) of San Jorge is classified as loamy (about 50%) or silt loam (about 50%); about 40% of the soil of the lower part (below 3,000 m) is clay, 40% between clay loam and sandy clay loam; the rest is sandy clay, loam, and sandy

loam. In Don Benito the predominant soil is loamy, and in San Francisco it is either loamy or silt loam.

Each composite forage sample came from 20-25 samples of the same forage species predominating and most frequently grazed by sheep in the different areas of the farms. Forage species collected were: vernalgrass (A. odoratum), native velvetgrass (H. lanatus L), imported velvetgrass (H. lanatus basyn), kikuyugrass (P. clandestinum), white clover (T. repens), tall fescue (F. arundinacea), and orchardgrass (D. glomerata). Each of the farms maintains about 3 sheep/ha/year under a rotational grazing system (appendix B table 19). There is not a fertilization program in San Jorge; however, some paddocks of the lower part receive nitrogen (in the form of Urea) at 50 kg ha^{-1} year. In Don Benito and San Francisco pastures are not fertilized; however, some paddocks take advantage of residual fertilization as a consequence of potato cropping. Forage samples were processed and analyzed for mineral content according to methods described by Fick et al. (1979).

Samples were collected from animals that were divided into three classes: lactating (or pregnant) ewes, lambs (1-4 months of age) and yearlings (10-14 months). The sheep were Criollo x Romney or Criollo x Corriedale in San Jorge and Criollo x Blackface in Don Benito and San Francisco.

Duplicate blood samples were obtained by jugular puncture and were collected in Monovette tubes (Saretedt,

West Germany). One tube contained the anticoagulent NH_4-heparin. The second tube was used for serum separation.

Bone biopsy samples were taken as described by Little (1972), with some modifications of the technique. The biopsy was taken without using a trephine; instead, a piece of bone approximately 2 cm in length was removed by cutting a section of rib using a small stainless steel bone shear.

Forage calcium, magnesium, potassium and sodium, serum calcium, magnesium, copper and zinc and bone calcium and magnesium were determined by atomic absorption spectrophotometry using a Perkin-Elmer AAS 5000 (Perkin-Elmer, 1980). Forage, serum and bone phosphorus were determined by the colorimetric method of Harris and Popat (1954). For nitrogen analysis, forage samples were digested using a modification of the aluminum block digestion procedure of Gallaher et al. (1975). In vitro organic digestibility (IVOMD) was performed by a modification of the two-stage technique (Moore and Mott, 1974).

Whole blood samples were processed at the Laboratorio de Investigaciones Medico Veterinarias (LIMV) of ICA in Bogota for hematocrit, hemoglobin and total and differential leucocyte counts. Hemoglobin concentration was obtained utilizing the oxyhemoglobin method, and to determine total leucocyte counts, a Coulter Counter model FN was utilized (Schalm and Nemi, 1986).

Data were analyzed by use of the Statistical Analysis System (SAS Institute, 1985). Soil and forage were analyzed

as a split-plot design, with farm as the main plot and season as the subplot. For forage, plant part was considered the subplot. Animal tissues were analysed as a split-plot design with animal class as the main plot and season as the subplot. Significance level was limited to .05 in all statistical analysis. Since the data were unbalanced, hypothesis testing was based on the Type IV Sum of Squares. Correlation coefficients among minerals were determined.

Results and Discussion

Soil Analyses

Soil analyses as related to season and farm are presented in table 5. Summary of the analysis of variance is shown in appendix 8 table 24. Soil organic matter was lower ($P<.05$) in San Jorge fare during the rainy season, but the pH was higher ($P<.05$) for the same farm during the dry season. Reid and Horvath (1980) indicated that maximum rate of cation absorption occure at pH 6-7. Soil acidity problems are associated with pH levels lower than 5.5 and the presence of exchangeable aluminum in the soil (Sanchez, 1976). Don Benito had a higher ($P<.05$) aluminum concentration during the rainy season; this farm had the lowest soil pH (4.8) of the three farms.

Among the macroelements, soils were most deficient in magnesium in relation to critical levels. Percentage of samples below the critical level of 30 ppm suggested by Rhue

TABLE 5. SOIL ORGANIC MATTER, pH, AND MACROMINERAL ANALYSES AS RELATED TO [illegible] FARM (DRY BASIS).

Variable	Critical level	Season	San Jorge Mean[a]	± S.E.[b]	% Def	Bue Bonita Mean	± S.E.	% Def	San Francisco Mean	± S.E.	% Def	Overall Mean	% Def
Organic matter %		rainy	10 4[f]	1 77		20 7[f]	1 12		33 3[f]	0 99		19 9	
		dry	13 4	2 10		15 6	± 73		31 1	0 91		18 2	
pH		rainy	5 1	0 04		4 0	± 00		4 0	0 01		5 0	
		dry	5 5[e]	0 03		4 0[f]	0 00		4 0[f]	0 01		4 1	
Al ppm		rainy	142[f]	37 9		575[g]	77 7		310[gf]	15 4		344	
		dry	94	9 66		439	91 4		424	13 5		364	
Ca ppm	< 31[f]	rainy	984[g]	168	4	242[f]	66 1	72	278[f]	44 3	10	448[h]	
		dry	968	120	0	211	122	50	293	44 4	10	5	
P ppm	< 17[d]	rainy	18 ±	3 79	58	41 6	10 5	17	19 0	3 14	44	29 4	
		dry	17 4	2 83	44	33 1	± 31	31	38 8	3 44	34	29 4	
Mg ppm	< 30[d]	rainy	141[f]	42 ±	24	24 2[f]	3 89	±0	13 3[f]	1 90	40	39 4	
		dry	147	28 4	44	11 2	2 13	94	20 4	1 04	100	68 1	
K ppm	< 82[g]	rainy	±5	10 0	44	103	8 71	6	±3	6 33	44	33 6	
		dry	108	11 3	24	73	4 55	100	91	4 56	70	43 1	
Na ppm		rainy	33 0[e]	3 60		± 2[f]	4 44		2 4[f]	0 0		11	
		dry	13 3	3 44		2 4	0 16		2 ±	± 32		8 8	

[a] Means based on the following number of composite samples: 20 20 (rainy dry) for San Jorge farm 19 14 (rainy dry) for [illegible] 20 20 (rainy dry) for San Francisco

[b] Standard error of mean

[c] Grunland (1976)

[d] Rhue and Kidder (1983)

[e-f] Means among farms in a row with different superscripts differ [illegible]

[g-h] Means between seasons in a column with different su[illegible]

These critical levels were in part for the major s[illegible] are presented only as [illegible]

and Kidder (1983), was 61 for the rainy season and 7% for the dry season. There were differences among farms with San Jorge having the highest levels (P<.05). Metson (1974) stated that there is some evidence that acidity aggravates a magnesium deficiency condition.

In general, San Jorge had higher concentrations (P<.05) during the rainy season for calcium, magnesium, and sodium. On the other hand, San Jorge had the lowest phosphorus level but it was not significant (P>.05). This element was 46% deficient in the rainy season and 39% in the dry season. Many tropical soils are generally reported to be deficient in phosphorus (Volkweiss, 1978).

Thirty seven % of the samples in the rainy season and 61% in the dry season were below the critical level of 62 ppm suggested for potassium by Rhue and Kidder (1983). Sodium presented very low levels in the three farms especially in Don Benito and San Francisco.

Forage Analyses

Forage macromineral, crude protein and IVOMD concentrations are presented in table 6. Summary of the analysis of variance is presented in appendix B table 25. Means and standard errors of each species in a season, are presented in appendix B tables 35 and 36. Even though the forage samples were separated by species, these could not be included in the statistical model because of the uneven occurrence of some of them which produced a large number of empty cells.

TABLE 6. FORAGE MACROMINERAL, CRUDE PROTEIN AND IVOMD CONCENTRATIONS AS RELATED TO SEASON AND FARM (DRY BASIS)

Variable	Critical level	Season	San Jorge Mean[a]	San Jorge S E[b]	San Jorge % Def.	Non Manlio Mean	Non Manlio S E	Non Manlio % Def.	San Francisco Mean	San Francisco S E.	San Francisco % Def.	Overall Mean	Overall % Def.
Ca %	< 0.21[c]	rainy	0.50	0.01	4	0.11	0.04	5	0.24	0.01	17	0.37	11
		dry	0.35	0.05	11	0.15	0.02	40	0.20	0.01	18	0.31	22
K %	< 0.5[c]	rainy	1.35	0.14	0	1.88	0.14	0	1.10	0.11	0	2.2[d]	
		dry	1.51	0.11	1	1.64	0.14	0	1.01	0.06	0	1.4	
Mg %	< 0.12[c]	rainy	0.11	0.01	11	0.11[e]	0.00	40	0.11[e]	0.00	11		
		dry	0.11[e]	0.01	50	0.08[e]	0.00	100	0.09[e]	0.00	01		
Na %	< 0.06[c]	rainy	0.04	0.00	00	0.01	0.00	100	0.05	0.00	89		
		dry	0.04	0.00	91	0.0[e]	0.01	01	0.01	0.00	91		
P %	< 0.16[c]	rainy	0.10	0.01	1	0.30	0.01	0	0.20	0.00	0	0	
		dry	0.17	0.01	47	0.10	0.01	60	0.12	0.00	05		
CP %	< 7[d]	rainy	11.5	1.00	0	20.0	0.91	0	11.4	0.89	5	18.4[d]	
		dry	11.1	0.79	11	14.1	1.01	7	10.5	0.01	10	11.0	
IVOMD %		rainy	58.1[f]	1.01		71.1[g]	3.00		11.1[e]	1.11		[illegible]	
		dry	11.6	1.36		58.9	1.50		51.0	1.1[illegible]		56	

[a] Means based on the following number of composite samples: 20, 29 (rainy, dry) for San Jorge; 2, 1 [illegible]
(rainy, dry) for San Francisco

[b] Standard error of means

[c] NRC (1980)

[d] [illegible]

[e] [illegible]

[f] [illegible]

[g] [illegible]

Lower limits of sheep requirements (dry matter basis) suggested by the NRC (1985) were used to calculate the percentage of deficient forage samples. Sodium was the most deficient macroelement in forage samples (93-94%) according to the critical level of .09% (NRC, 1985). Potassium was the least deficient (only 1%) element in forage samples This element is often associated with high levels of nitrogen and moisture in lush, cool-season grasses (Boling et al., 1979). Magnesium was 31 and 75% deficient for rainy and dry season, respectively. Phosphorus was only 3% deficient in the rainy season but 62% in the dry season. Underwood (1981) stated that phosphorus deficiency is the most widespread and economically important of all the mineral deficiencies affecting grazing livestock. Thirteen and 22% of forage samples were calcium deficient in the rainy and dry seasons, respectively . The results of this study are in contrast to the results of many researchers in the Latin American tropics who have reported relatively low calcium and extremely deficient phosphorus forage concentrations (McDowell, 1985).

Surprisingly, only 1% of the samples in the rainy season and 11% in the dry season were deficient for crude protein, according to the critical value of 7% suggested by Minson and Milford (1967). The high protein concentration found in this study agrees with that of Laredo and Anzola (1986) who determined the crude protein level in temperate grasses similar to the ones used in this research. Sanchez

(1976) states that organic matter in the soil supplies most of the nitrogen and half of the phosphorus taken up by unfertilized crops; Sillanpaa (1982) stated that the correlation between the nitrogen content of the plant and total soil nitrogen is relatively good.

Magnesium in San Jorge forage samples was higher ($P<.05$) during the dry season but the deficiency for this fare was as high as 50%. Michael (1962) reported that serum magnesium levels in sheep were not correlated with herbage magnesium content, but Fontanot (1982) stated that a magnesium deficiency in ruminants may result from low magnesium concentrations in feeds or a reduction in biological availability of dietary magnesium. Nitrogen level, stage of maturity, excessive potassium level, form of magnesium, and amount of readily fermentable carbohydrate have been considered as components of magnesium utilization (Rosaro et al., 1980).

Calcium, potassium, phosphorus, sodium and crude protein concentrations were not different ($P>.05$) among the three farms. The IVOMD was lower ($P<.05$) for San Jorge during the rainy season but not during the dry season. The values of IVOMD for the forages in San Jorge were not low (58.7 and 57.6) and those for Don Benito (71.1 and 58.9) and San Francisco (72.6 and 53.8) are considered high, which implies that the animals were receiving good quality forage especially during the rainy season. Since IVOMD values were relatively high it seems that production of forage DM/ha in

tha paramo is more of a limitation to animal performance than is forage quality. In a previous study, Laredo et al. (1989) found that the production of DM/ha in Don Benito was 2.8 ton and 2.0 ton for H. lanatus hayn (imported cultivar) and H. lanatus L (native cultivar); in San Francisco the production of DM/ha was 2.8 ton and 0.8 ton, respectively. These values were low for the standards of the grass (Watt, 1978) and even lower when compared to other temperate grasses.

There was a marked effect of season on all macroelements studied. Magnesium, potassium, phosphorus and crude protein were lower (P<.05) during the dry season. Although sodium was not different (P>.05) between seasons, concentrations indicated that there was a serious deficiency at all times. Calcium had similar values for both seasons. McDowell et al. (1983) stated that as plants mature, mineral concentration declines due to a natural dilution process and translocation of nutrients to the root system; in most circumstances, magnesium, phosphorus, potassium and sodium decline as the plant matures. Crude protein declined from 18.4% to 12% (P<.05). In vitro organic matter digestibility also declined, from 66.7% to 56.7%, but the difference was not significant (P>.05).

Animal Tissue Analyses

Blood serum and bone macromineral concentrations as related to season and farm and as related to season and

animal class are presented in tables 7 and 8. Results of analysis of variance are presented in appendix 8 table 26.

Blood serum. No differences were found (P>.05) among farms for serum calcium and phosphorus during both the rainy and dry seasons, and for magnesium during the rainy season. Magnesium had a higher value (P<.05) in farm San Jorge (2.18 mg/dl) than farm San Francisco (1.93 mg/dl) during the dry season.

Differences (P<.05) among animal classes were found for magnesium and phosphorus. Lambs had higher (P<.05) concentrations for serum phosphorus than ewes (5.2, 5.6 vs 3.6, 2.5 mg/dl) in the rainy and dry seasons, respectively, and higher (P<.05) than yearlings but only in the dry season (4.0 mg/dl). On the contrary, lambs had lower (P<.05) values for serum magnesium than yearlings in the dry season. There were no differences (P>.05) for serum calcium among the three animal classes.

The general tendency was for the dry season to have lower values of calcium, magnesium and phosphorus; nevertheless, phosphorus was the only element statistically affected (P<.05) by season (4.71 vs 3.99 mg/dl).

The incidence of calcium deficiency as percentage of samples below critical levels (McDowell et al., 1984) was 3% for the rainy season and 94% for the dry season. The incidence of deficiency for San Jorge, Don Benito and San Francisco during the dry season was 100, 97 and 87%, respectively; the incidence of deficiency for ewes, lambs

TABLE 7. BLOOD SERUM AND BONE MACROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND FARM[1]

Variable	Critical level[2]	Season	San Jorge Mean[3]	S E[4]	n Def	Don Benito Mean	S E	n Def	San Francisco Mean	S E	n Def	Overall Mean	% Def
Serum													
Ca mg/dl	< 8	rainy	10 00	0 17	7	0 55	0 18	0	10 34	0 17	0	70 1	1
		dry	0 20	0 10	700	0 00	= 17	07	0 49	0 10	07	0 7=	94
o mc/dl	< 4 5	rainy	4 77	= 71	57	4 96	0 20	47	4 17	0 17	5=	0 71[d]	51
		dry	7 =7	0 77	71	4 41	0 23	07	7 76	0 7=	67	7 99	67
Mg, mg/dl	< 2	rainy	7 71	0 08	0	7 0=	0 07	37	7 17	0 05	25	7 14	22
		dry	7 10[d]	= 06	41	1 98[de]	0 0=	47	1 =1[e]	= 05	07	7 07	51
Mean 10 o , fol-fruel													
Ash =	< 56 0	rainy	=2 1	0 51	100	67 7	0 ==	700	61 4	0 47	100	67 0	100
		dry	5= 4	1 07	0=	05 2	7 72	88	67 4	= 7=	96	61 7	00
Ca =	< 7= 5	rainy	72 00	0 2=	100	22 1=	= 7=	196	76 99	0 1=	700	22 1	700
		dry	20 15	= 56	100	77 34	1 26	00	21 00	0 2=	100	71 7	07
f =	< 11 5	rainy	7 =7	0 27	100	0 76	0 =7	=5	7 26	0 31	100	7 32	97
		dry	= 07	0 20	700	0 70	0 55	94	6 01	0 36	100	= 77	
Mg =		rainy	= 17	= 01		0 38	0 07		0 35	0 01		0 36	
		dry	0 72	0 00		0 47	0 07		0 29	0 01		= 77	

[1] McDowell et al 11984)

[2] Means based on the following number of samples serum 36, 74 (rainy dryl for San Jorge farms; 71 14 (rainy dry) for Don Benito and 74 00 (rainy dryl for San Francisco Bone 26 17 (rainy dryl for San Jorge; 22 7= (rainy, dry) for Don Benito and 25 20 (rainy dry for San Francisco.

[3] Standard error of means

[4] Means among farms in a row with different superscripts differ (P< 05)

[5] Means between seasons in a column with different superscripts differ (P< 05)

TABLE 5. BLOOD SERUM AND BONE MACROMINERAL CONCENTRATIONS AS [illegible] AND ANIMAL CLASS.

Variable	Critical level[a]	Season	Ewes			Lambs			Yearlings			Bermuda	
			Mean[b]	S E[c]	% Def	Mean	S E	% Def	Mean	S E	% Def	Mean	% Def
Serum													
Ca mg/dl	< 8	rainy	9 44	0 19	0	10 14	4 44	4	40 53	0 88	4	10 1	[illegible]
		dry	5 44	0 14	400	7 14	4 44	44	6 05	0 88	100	6 1	[illegible]
P mg/dl	< 4 4	rainy	4 44[e]	4 44	84	5 44[d]	0 38	38	5 58[d]	0 24	44	4 71[f]	[illegible]
		dry	4 54[f]	0 44	47	4 02[d]	0 26	19	4 90[f]	0 12	71	4 99[f]	[illegible]
Mg mg/dl	< 4	rainy	4 45	0 04	27	4 04	0 09	29	4 41[g]	0 04	44	2 14	[illegible]
		dry	1 96[hm]	0 04	54	1 44[h]	0 04	41	4 14[g]	0 04	35	2 44	51
Bone (0 M , fat free)													
Ash %	< 66 0	rainy	04 2[fl]	0 24	100	60 3[f]	0 00	100	61 7[e]	0 47	400	42 4	400
		dry	45 4	0 00	20	50 4	1 41	100	64 4	0 51	95	41 4	89
Ca %	< 24 5	rainy	44 0	0 14	100	24 3	0 20	100	41 5	0 41	100	44 1	100
		dry	42 4	0 20	100	10 4	0 50	400	21 4	0 52	95	41 4	94
P %	< 11 5	rainy	4 84	0 42	100	9 44	0 50	100	7 60	0 47	00	7 12	99
		dry	4 32	0 10	100	4 44	0 20	100	1 01	0 32	98	[illegible]	[illegible]
Mg %		rainy	0 34	0 01		0 00	0 01		4 34	4 44		[illegible]	
		dry	0 34	0 01		0 20	0 01		4 44	4 04		[illegible]	

[a] McDowell et al (1983).

[b] Means based on the following number of samples: serum 17, 41 (rainy, dry) for ewes; 21, 47 (rainy, dry) for lambs and 55, [illegible] dry) for yearlings; bone 34, 39 (rainy, dry) for ewes; 14, 43 (rainy, dry) for lambs and 35, 44 (rainy, dry) for yearlings.

[c] Standard error of means.

[d, e, f] Means among animal classes in a row with different superscripts differ (P<0.05).

[g, h] Means between seasons in a column with different superscripts differ (P<0.05).

snd yearlings wss 100, 74, and 100%, reapectivsly during the dry season. Ths high incidsnce of ssrum samples below ths critical lsvsl indicated thst the sheep had a very savere calcium deficiency during ths dry sssson. Shssp snd csttle hsvs hormonsl mschanisms which maintain blood calcium concentrations within narrow limits by adjusting the proportion of distary calcium absorbed and, whsn dietary calcium is insdsquate, by rssorbing calcium from body rssarves in ths sksleton (Rowlands, 1980). Blsok at al. (1973) reported thst serum calcium concsntrations msy be dirsctly affsctad by distsry calcium intake, and Staavens at al. (1971) reportad thst serum calcium concsntrations srs affsctad mors by the amounts of phosphorus and magnesium in the dist than by calcium itself. Serum calcium, however, is influsncad only by ssvsrs dsficiency, snd calcium dietary levels may ba a more adsquats criterion in assessing statum of calcium (CMN, 1973).

Serum inorganic phosphsts was dsficient in 51% of samplss during ths rsiny sesson snd of 67% during the dry sssson according to the lsvsl of 4.5 mg/dl suggsstsd as a critical concentrstion by McDowell st sl. (1984). Dsficiency of phosphorus for farms San Jorge, Don Banito, and San Frsncisco wss 53, 42 snd 58% for the rainy season and 71, 62, snd 67% for the dry ssason, rsspsctivsly. Dsficisncy of serum phosphorus for swss, lsmbs snd yearlings wss 84, 38 snd 23% for ths rainy season and 97, 19 and 72% for the dry seasen. Plasms inorganic phosphats

concentrations are maintained by absorption of phosphorus from the gut, and there is no specific mechanism for bone phosphorus resorption (Jacobson et al., 1972); positive relationships between dietary phosphorus intake and plasma inorganic phosphate concentrations have been observed (Rowlands, 1980). However, serum or plasma phosphate is not recommended as a practical criterion for assessing phosphorus status in cattle or sheep (CMN, 1973).

Overall incidence of samples below the critical level of 2 mg/dl of magnesium suggested by McDowell et al. (1984) was 22% for the rainy season and 51% for the dry season. The deficiency for farms San Jorge, Don Benito and San Francisco was 41, 47 and 61% for the dry season. For ewes, lambs and yearlings the deficiency was 52, 81 and 35% for the dry season. In contrast to calcium, serum magnesium concentration depends mainly on the dietary intake of available magnesium (Rowlands, 1980). Levels below 2 mg/dl in plasma are classed as hypomagnesaemic, but magnesium concentration in blood serum does not fall until there is a severe deficiency (CMN, 1973).

Bone. Bone macromineral concentrations as related to season and farm and as related to season and animal class are presented in tables 7 and 8. Summary of analysis of variance is presented in appendix B table 26.

There was no season nor farm effect ($P>.05$) for any of the bone parameters studied with the exception that ash

during the rainy season had a variation among animal classes. Ewes had higher (P<.05) ash concentrations than yearlings (64.2 vs 61.7%), and lambs lower (P<.05) than both classes at 60.3%.

Individual evaluation of samples indicated that ash concentrations below a critical level of 66.8% (McDowell et al., 1984), was 100% during the rainy season and 89% during the dry season. Spongy bone of the axial skeleton are the first to demineralize in periods of negative balance (Little, 1972).

Calcium mean concentrations were below the suggested critical level of 24.5% (McDowell et al., 1984). Deficiencies were 100% for the rainy season and 97% for the dry season. This is in agreement with the results observed by other researchers (Knebush et al., 1986, Tejada et al., 1987) who reported that when animals were evaluated for calcium status, using blood serum and bone samples, a consistently higher number of animals were determined to be below the critical levels based on bone analysis when compared to critical levels in serum. Furthermore, this supports the concept that cattle or sheep resist depletion of plasma calcium through mobilization of bone calcium, thus making bone a more accurate indicator of calcium levels in the animal.

Mean rib bone phosphorus was 98% deficient in both rainy and dry seasons, according to the critical level of 11.5% (McDowell et al., 1984). This is in agreement with

the results of other researchers who worked with cattle in the tropics (Tejada et al., 1987, Vargas et al., 1984). Adequate forage phosphorus concentration appears to be reflected more accurately in plasma phosphate than bone, even though many researchers prefer bone phosphorus over serum concentrations to evaluate the phosphorus status of an animal (McDowell et al., 1983).

Bone magnesium concentrations were similar among farms and among animal classes. Cohen (1987) suggested that bone magnesium may be useful in assessing magnesium status in grazing livestock.

Correlation Coefficients of Minerals

Blood serum and bone macromineral correlation coefficients as related to season are presented in appendix 8 table 28. Correlation coefficients ($P<.05$, $r>|.50|$) in serum were calcium-phosphorus (r=.76), calcium-iron (r=.65) and calcium-zinc (r=.77) during the dry season. For bone, the correlations were calcium-ash (r=.79) during the rainy season, calcium-phosphorus (r=.80), and calcium-ash (r=.97) during the dry season.

Correlation coefficients between serum and bone minerals as related to season are presented in appendix 8 table 29. Correlation coefficients between serum and bone macrominerals were observed among serum phosphorus-bone magnesium (r=.84) and serum magnesium-bone phosphorus (r=.85) during the rainy season.

In general, mineral concentrations among animal tissues did not correlate with each other with a correlation coefficient greater or equal to |.50| at the probability level of .05. This demonstrated the problem of finding significant correlation coefficients between soil, forage and animal tissues (Conrad et al., 1980).

Hematological Measurements

Hemoglobin and hematocrit concentrations and leucocyte counts as related to season and farm are presented in table 9. Summary of analysis of variance is in appendix B table 27.

San Jorge had higher (P<.05) total leucocyte counts (16,838/ul) than Don Benito (7,605/ul) and San Francisco (8,107/ul) during the rainy season. During the dry season the values were much lower for San Jorge and different only to San Francisco.

Total leucocyte counts in San Jorge during the rainy season exceeded the normal limit of range in absap set by Schalm and Nami (1986) of 12,000/ul. Differential leucocyte count in the same farm, during the rainy season, showed that the percentage of lymphocytes exceeded the limit of range of 75% (Schalm and Nami, 1986).

There were no differences (P>.05) among animal classes for any of the hematological measurements studied, but lambs in the rainy season exceeded the limit of range for total leucocytes (Schalm and Nemi, 1986) and also exceeded the limit of range of 75% for lymphocytes but were below the

TABLE 9. HEMOGLOBIN, HEMATOCRIT CONCENTRATION AND LEUCOCYTE COUNTS AS RELATED TO SEASON AND FARM.

Variable	Range of Values[a]	Season	San Jorge Mean[b]	San Jorge S.E.[c]	San Benito Mean	San Benito S.E.	San Francisco Mean	San Francisco S.E.	Overall Mean
Hematocrit %	27-48	rainy	34.0	0.51	40.8	0.83	40.3	0.62	38.0
		dry	34.8	0.86	33.6	0.74	35.8	0.88	37.8
Hemoglobin g %	9-18	rainy	11.8	0.18	13.6	0.33	13.8	0.33	12.6
		dry	11.8	0.13	11.3	0.47	13.8	0.20	12.6
Leucocytes /µl	8800-12000	rainy	10430[d]	997	7898[e]	13	8183[e]	201	11456
		dry	7233[e]	116	8431[d]	349	8888[d]	186	8069
Neutrophils %	18-50	rainy	30.8	1.21	18.6	1.9	26.0	1.93	18.0
		dry	8.8	.45	2.1	1.98	11.8	5.89	30.3
Lymphocytes %	38-78	rainy	64.8	1.83	76.*	3.84	69.0	1.88	73.1
		dry	31.5	3.68	73.1	3.23	78.3	2.63	71.8
Monocytes %	0-6	rainy	0.72	0.18	1.58	0.31	3.66	0.66	1.3
		dry	1.11	0.23	1.36	0.24	0.83	0.13	1.0
Eosinophils %	0-10	rainy	1.33	0.88	3.26	0.79	3.66	0.97	3.8
		dry	3.56	0.50	2.66	3.65	3.66	0.83	3.3
Basophils %	0-1	rainy	0.66		0.00	0.06	0.66		0.01[e]
		dry	0.83	0.11	0.76	0.17	0.33	0.66	0.88[d]

[a] Schalm and Noel (1976)

[b] Means based on the following number of samples: 26 30 (rainy dry) for San Jorge; 33 29 (rainy dry) for San Benito and 21 20 (rainy dry) for San Francisco

[c] Standard error of means

[d,e] Means among farms in a row with different superscripts differ ($P < 0.05$)

range of 10% for mature neutrophils percentage. These lambs exhibited slight to moderate leucocytosis, defined as WBC values of 13,000 and 20,000/ul (Holman, 1944) and could mean that an infectious process was taking place in the lambs of San Jorge at the time the samples were taken.

Summary and Conclusions

A study was conducted to determine the macromineral status of three sheep farms located on the paramo region of the Cordillera Oriental in Colombia, and to compare animal classes (pregnant-lactating ewes, lambs, and yearlings). Soil, forage, blood and rib bone samples were collected to correspond to the end of the rainy season (May-June, 1987) and the middle to end of the dry season (February, 1988).

Season affected (P<.05) soil concentrations of calcium and sodium and forage concentrations of magnesium, potassium, phosphorus and crude protein. Soil analyses showed high organic matter (19%) and low pH values (5.0) for the three farms. Magnesium was the most deficient macroelement in both seasons with an overall deficiency of 70%, followed by potassium with 52% of the samples deficient; phosphorus was 46% deficient. Sodium was the most deficient macroelement in forage samples with 93% overall deficiency; phosphorus was deficient only in the dry season (62%) and magnesium had 53% overall deficiency. Crude protein was deficient in 6% of the forage samples.

Blood serum analyses showed an overall phosphorus deficiency in 59% of the samples, and a calcium dry season deficiency of 94%. Bone was 98% deficient in both calcium and phosphorus, with ash percentage being also very deficient (95%). Differences (P<.05) among animal classes were found in serum phosphorus in both seasons (lambs were higher in phosphorus), in serum magnesium in the dry season (lambs were lower in magnesium), and bone ash in the rainy season (lambs were lower in ash percentage).

Among soil minerals and the corresponding forage minerals only calcium and magnesium had positive correlation (P<.05, r > |.50|) coefficients for both seasons. In general, macrominerals between animal tissues did not correlate with each other.

Based on these analyses it was concluded that macromineral status of sheep on the pasture was deficient and supplementation programs should provide common salt, calcium, phosphorus and magnesium.

CHAPTER V
MINERAL STATUS OF SHEEP IN THE PARAMO REGION OF COLOMBIA. II. MICROELEMENTS

Introduction

It has been reported (McDowell and Conrad, 1977) that ruminants grazing forages in severely mineral-deficient areas may even be more limited by this condition than either a lack of energy or protein, and that trace element deficiencies or imbalances in soils and forages are responsible for low production and reproduction among grazing livestock (McDowell et al., 1984). As grazing livestock usually do not receive mineral supplementation except for common salt, they must depend almost exclusively upon forages for their requirements. Only rarely, however, can forages completely satisfy all mineral requirements (Miles and McDowell, 1983).

It has been shown from a region in the Colombian paramo that forages are low in copper, cobalt and zinc and high in iron and molybdenum and that this imbalance in micronutrients might be the cause for the low production of the sheep in the area (Proyecto Ovino Colombo Britanico, 1979).

The objectives of this study were to evaluate the micromineral status of grazing sheep and to determine the microelement status of soil and forages of three sheep farms as related to the two seasons prevailing in the paramo region of Colombia.

Materials and Methods

Soil, forage and animal tissue samples were collected from three sheep farms in the Cordillera Oriental of the paramo of Colombia. Sampling periods corresponded to the end of the rainy season (May-June, 1987) and the middle to end of the dry season (February, 1988).

A total of 113 composite soil, 131 composite forage, 207 serum and 113 liver biopsy samples were obtained for each of the sampling periods.

Each composite soil sample for each farm was obtained from 8-12 samples. A sampling technique described by Mahia (1978) was used. Soil samples were analyzed by standard methods in the Laboratorio Nacional de Suelos of ICA in Bogota for boron, copper, iron, manganese and zinc. Minerals were extracted from the soil samples with a double acid extracting solution (.025N H_2SO_4 and .05 N HCl). Soil mineral concentrations were determined by atomic absorption spectrophotometry (Perkin-Elmer, 1980).

Based on texture, the soil in the upper part (above 3,000 m) of San Jorge is classified as loamy (about 50%) or

silt loam (about 50%); in the lower part (below 3,000 m) about 40% of the soil is clay, 40% a combination of clay loam and sandy clay loam, and the rest is sandy clay, loam, and sandy loam. In Don Benito the predominant soil is loamy, and in San Francisco is either loamy or silt loam. Each composite forage sample was obtained from 20-25 samples of the same forage species predominating and most frequently grazed by sheep in the different areas of the farm. The forage species collected were vernalgrass (A. odoratum), a native cultivar of velvetgrass (H. lanatus L), an imported cultivar of velvetgrass (H. lanatus basyn), kikuyugrass (P. clandestinum), white clover (T. repens), tall fescue (F. arundinacea), and orchardgrass (D. glomerata). Appendix B table 21 shows the detailed number of soil and forage species; proper identification of paddocks and of forage species is in appendix C. Forage samples were processed and analyzed for mineral content according to methods described by Fick et al. (1979).

Each of the farms maintains about 3 sheep/ha/year under a rotational grazing system. There is not a fertilization program in San Jorge; however, some paddocks in the lower part of the farm receive nitrogen (in the form of Urea) at 50 kg/ha/year. In Don Benito and San Francisco pastures are not fertilized; however, some paddocks take advantage of residual fertilization as a consequence of potato cropping.

Samples were collected from animals that were divided into three classes: lactating (or pregnant) ewes, lambs (1-

4 months of age) and yearlings (10-14 months of age). The sheep were Criollo x Romney or Criollo x Corriedale in San Jorge and Criollo x Blackface in Don Benito and San Francisco.

Blood plasma and liver biopsy samples were collected from the animals at each farm as described by Fick et al. (1979) and McDowell et al. (1983).

Selenium analyses of soil, forages, blood and liver were carried out using a fluorometric technique described by Whetter and Ullrey (1978)

Forage iron, copper, manganese and zinc, blood copper and zinc, and liver copper, iron, manganese and zinc were determined using atomic absorption spectrophotometry using a Perkin-Elmer AAS 5000 (Perkin-Elmer, 1980). An atomic absorption spectrophotometer equipped with a graphite furnace and Zeeman background corrector (Perkin-Elmer Model 3030) was used to determine forage and liver cobalt and molybdenum.

Data were analyzed by use of the Statistical Analysis System (SAS Institute, 1985). Soil and forage were analyzed as a split-plot design, with farm as the main plot and season as the subplot. For forage, plant part was considered as the subplot. Animal tissues were analyzed as a split-plot design with animal class as the main plot and season as the subplot. Significance level was limited to .05 in all statistical analyses. Since the data were unbalanced, hypothesis testing was based on the Type IV Sum

of Squares. Correlation coefficients between minerals were estimated.

Results and Discussion

Soil Analyses

Soil micromineral analyses as related to season and farm are presented in table 10. Summary of analysis of variance is shown in appendix B table 30. Description of paddocks and forage species are in appendix C.

Soil iron was higher ($P<.05$) in Don Benito than San Francisco during the dry season. A similar trend was found during the rainy season. According to the critical level of 2.5 ppm set by Viets and Lindsay (1973) none of the samples for the three farms were deficient in iron. These concentrations were considerably in excess of normal values, and could result in a reduced availability of phosphorus to plants (Lindsay, 1972).

San Francisco farm had a lower ($P<.05$) soil zinc value than the other two farms during the rainy season. Individual evaluation of samples based on a critical level of 1 ppm when pH is below 6.5 (Rhue and Kidder, 1983) indicated that none of the samples during the rainy season, and only 13% during the dry season were deficient for this element.

San Francisco had a lower ($P<.05$) soil boron concentration than the other two farms during the dry

TABLE 10. SOIL MICROMINERAL ANALYSES AS RELATED TO SEASON AND FARM (DRY BASIS).

Variable	Critical level	Season	San Jorge Mean[a]	San Jorge S.E.[a]	San Jorge % Def	Don Benito Mean	Don Benito S.E.	Don Benito 2 Def	Soj fractions Mg22	Soj fractions Al %	Soj fractions % Def	Overall Mean	Overall 2 Def
Fe ppm	< 2.5[c]	rainy	451[fg]	40.2	0	680	77.0	0	411	32.7	0	505	0
		dry	787[f]	31.2	0	922[f]	122	0	224[g]	12.2	0	286	0
Cu ppm	< 0.2[d]	rainy	2.0	0.22	0	2.0	0.79	0	1.0	0.12	0	1.80	0
		dry	2.0	0.26	0	0.6	0.08	57	0.4	2.12	2	1.12	17
Mn ppm	< 5[d]	rainy	12.5	2.11	30	0.2	0.87	23	5.4	0.62	58	0.05	64
		dry	10.5	1.22	12	4.2	0.49	79	4.0	0.32	13	2.72	59
Zn ppm	< 1[d]	rainy	2.2[f]	0.22	0	2.0[f]	0.16	0	1.2[g]	2.11	3	2.20[h]	0
		dry	2.2	0.22	14	1.0	0.23	21	1.1	0.04	2	1.63[h]	
Ca[b] ppm	< 2[c]	rainy	0.0)		100	0.05		106	0.02		100		
B ppm	> 4[c]	rainy	0.28[f]	0.03	22	0.28[f]	0.02	80	0.28	0.03	80	0.4	0
		dry	0.15[f]	0.02	88	0.36[f]	0.02	79	0.21[g]	0.02	100	[illegible]	[illegible]

[a] Means based on the following number of composite samples: 20 in 20 (rainy dry) for San Jorge farms; 15 in 12 (rainy dry) for Don Benito and 2 [illegible] (rainy dry) for San Esteban.

[b] Standard error of mean.

[c] Viets and Lindsay (1973).

[d] Rhue and Kidder (1221).

[e] McClure (1976).

[f,g] Means within pairs in a row with different superscripts differ (P<0.05).

[h] McDowell et al. (1969).

[i] Calcium was not included in the statistical analyses.

[j] Means between pairs in a column with different superscripts differ (P<0.05).

These critical levels were derived for the more sandy soils of Florida and may not be appropriate [illegible] Use below them only as guides or approximations of critical concentrations.

season. The percent deficiency of this element, according to the value of 0.4 ppm suggested by Gammon (1976) was 85% for the rainy season and 80% for the dry season. Boron has been established as essential for higher plants and is added frequently to fertilizers for plants with high requirements such as alfalfa (NRC, 1980).

Farm was not a source of variation (P>.05) for copper and manganese during both seasons, for boron and iron during the rainy season and for zinc during the dry season. The only microelement affected (P<.05) by season was zinc which had a lower value during the dry season. Copper, iron and manganese had lower values during the dry season but were not different (P>.05).

The percentage of samples below the critical level of .3 ppm for copper (Rhue and Kidder, 1983) was none during the the rainy season and 17% during the dry season. Most of the deficient samples for copper were found in Don Benito, with 57% of the samples deficient during the dry season.

For manganese, the percentage of samples below the critical level of 5 ppm (Rhue and Kidder, 1983) was 44% during the rainy season and 59% during the dry season. Among farms the deficiency was San Jorge, 30 and 35; Don Benito 53 and 79; San Francisco, 50 and 70% for rainy and dry seasons respectively.

Soil selenium was not included in the statistical analysis but the concentrations for the three farms during the rainy season are presented in table 10 The selenium

concentration of soil reflects that of the parent material (Reid and Horvath, 1980). Some research has indicated that soil selenium concentrations of less than .5 ppm are found in areas where selenium deficiency in livestock occurs (McDowell et al., 1989). Based on this critical level, all samples were deficient in selenium.

Forage Analyses

Results of forage micromineral analyses as related to farm and season are presented in table 11. Summary of analysis of variance is shown in appendix 8 table 31.

Forage cobalt was higher (P<.05) in San Jorge in comparison to Don Benito and San Francisco during the rainy season. A similar tendency was observed during the dry season, but was not significant (P>.05). According to the critical level of .1 ppm suggested by the NRC (1985), 79% of the samples were deficient in cobalt during the rainy season and 95% during the dry season. Among farms deficiencies were San Jorge, 54 and 90; Don Benito, 100 and 100; San Francisco 95 and 100% for rainy and dry seasons, respectively. McDowell et al. (1982) reported that, with the exception of phosphorus and copper, cobalt deficiency is the most severe mineral limitation to grazing livestock in many tropical countries, and sheep are more severely affected than other ruminant species.

Manganese concentration was higher (P<.05) in San Francisco in comparison to San Jorge during the dry season. According to the value of 20 ppm (NRC, 1985) only 1% of the

TABLE 11. FORAGE MICROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND FARM (DRY BASIS).

Variable	Critical Level	Season	San Jorge			Don Benito			San Francisco			Overall	
			Mean[a]	S.E.[b]	% Def	Mean	S.E.	% Def	Mean	S.E.	% Def	Mean	% Def
Cu, ppm	< 7[c]	rainy	7.53	0.65	38	0.91	0.43	65	0.97	0.64	79	7.10	57
		dry	1.92	0.14	97	3.07	0.51	47	1.70	0.16	95	7.47	4
Co, ppm	< 0.1[c]	rainy	0.11[e]	0.01	54	0.01[f]	0.00	100	0.04[f]	0.00	45	0.06	88
		dry	0.08	0.02	98	0.01	0.00	100	0.01	0.00	100	0.05	78
Fe, ppm	< 30[d]	rainy	313	14.1	14	186	14.5	0	379	9.2	0	184	
		dry	119	11.7	0	104	11.1	0	156	13.2	0	115	
Mn, ppm	< 20[c]	rainy	167	16.0	4	714	77.1	0	231	26.4	0	303	
		dry	111[f]	17.4	0	301[e]	21.4	0	402[e]	17.5	0	304	
Mo, ppm	> 0[d]	rainy	0.87[f]	0.14		1.59[g]	0.10	-	0.88[f]	0.06		1.41	
		dry	0.44	0.09		0.79	0.10		0.44	0.11		0.58	
Se, ppm	< 0.1[c]	rainy	0.11[f]	0.01	54	0.15[g]	0.01	25	0.09[f]	0.01	53	0.33	14
		dry	0.10	0.01	70	0.16	0.01	51	0.08	0.01	89	0.11	18
Zn, ppm	< 20[c]	rainy	14.4	2.24	11	24.3	1.11	20	19.4	0.87	63	25.7	6
		dry	14.1	1.13	57	26.1	1.10	11	20.4	1.05	40	22.2	4

[a] Means based on the following number of sampling: 20, 20 (rainy, dry) for San Jorge; 30, 15 (rainy, dry) for Don Benito and [illegible] (rainy, dry) for San Francisco.

[b] Standard error of means.

[c] NRC (1980).

[d] McDowell et al. (1984).

[e, f] Means among farms in a row with different superscripts differ (P<0.05).

[g, h] Means between seasons in a column with different superscripts differ (P<0.05).

samples were deficient during the rainy season and none during the dry season. All values were in excess of the requirements for sheep. Several studies indicate the ruminant has a high tolerance for manganese (Hansard, 1983); mineral imbalances typified by excesses of iron and manganese may interfere with metabolism of other minerals (Lehdonsakojo et al., 1980). The farm means were well below the maximum tolerable level of 1000 ppm (NRC, 1985).

Forage selenium was higher ($P<.05$) in Don Benito compared with the other two farms during the rainy season. Forty-three % of the samples during the rainy season and 88% during the dry season were deficient according to the .1 ppm value suggested for sheep by NRC (1985). Among farms the deficiencies were: San Jorge, 50 and 70; Don Benito, 28 and 53; San Francisco, 53 and 80% for rainy and dry seasons, respectively. Underwood (1981) considered that for all ordinary grasses and legumes the primary determinant of selenium concentration was the level of available selenium in the soil.

Forage molybdenum concentrations were different ($P<.05$) among farms during the rainy season. Don Benito had a higher value in comparison with the other two farms. However, none of these values were above the 8 ppm (dry basis) suggested as a toxic limit (McDowell et al., 1984). According to Suttle (1988) only a small increase in molybdenum and sulfur concentrations will cause major reduction in copper availability. He reported that

differences of 3 ppm of molybdenum (from 1 to 4 ppm) and .5 ppm of sulfur (from 2.5 to 3) between two pastures are sufficient to reduce copper availability to one half.

Farm was not a source of variation (P>.05) for copper, iron and zinc during both seasons; for cobalt, molybdenum and selenium during the dry season and for manganese during the rainy season. Season was a source of variation (P<.05) for the following microelements: cobalt, copper, manganese and molybdenum: all except manganese had lower (P<.05) concentrations during the dry season. The levels of selenium and zinc were also lower during the dry season, but were not significant (P>.05). On the contrary, iron and manganese were higher during the dry season.

The percentage of samples below the critical level of 7 ppm suggested by NRC (1985) for copper was 57% for the rainy season and 94% for the dry season. Among farms the deficiencies were as follows: San Jorge, 36 and 97: Don Benito, 65 and 87, San Francisco, 79 and 95% for rainy and dry seasons, respectively. The results of this study showed that copper:molybdenum ratio was at least 6:1 in San Jorge and San Francisco and 4:1 in Don Benito, and that molybdenum levels were not higher than 4 ppm in any case. Copper concentration was marginal in forages during the rainy season and deficient during the dry season. The animals, in this situation, might respond to appropiate copper supplementation.

Evaluation of samples based on the dietary zinc requirement of 20 ppm (NRC, 1985) indicated deficiencies of 26% during the rainy season and of 45% during the dry season. Among farms, the deficiencies were: San Jorge, 11 and 57; Don Benito, 20 and 13; San Francisco, 63 and 50% for rainy and dry seasons. Ruminants have exhibited signs of zinc deficiency when grazing forage containing 20 to 30 ppm of zinc (Pierson, 1966). However, a marginal zinc deficiency appears to be a more widespread occurrence (Spears, 1989).

Forage samples evaluated on the levels of 30 ppm of iron (NRC, 1985) showed that only 6% were deficient during the rainy season and none during the dry season. This is in agreement with the zero incidence of iron deficiency found in the soil samples. McDowell (1985) stated that ruminant animals are not likely to suffer from iron deficiency. None of the samples reached the maximum tolerable level of 500 ppm suggested for sheep by the NRC (1985).

Animal Tissue Analyses

Blood serum and liver mineral concentrations as related to season and farm are presented in table 12, and as related to season and animal class are in table 13. Summary of analysis of variance of serum and liver minerals is shown in appendix B table 32.

Blood serum. There were no significant farm by animal class interactions ($P>.05$) for any of the serum minerals considering seasons separately. Iron,

TABLE 12. BLOOD SERUM AND LIVER MICROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND FARM.

Variable	Critical level[a]	Season	San Jorge			Don Benito			San Francisco			Overall	
			Mean[b]	S.E.[c]	% Def	Mean	S.E.	% Def	Mean	S.E.	% Def	Mean	% Def
Farm													
Cu ppm	< 0.6	rainy	0.79	0.04	19	0.69	0.04	38	1.04	0.04	4	0.82	
		dry	1.01	0.04	0	1.20	0.05	0	1.44	0.04	0	1.20	
Zn ppm	< 0.4	rainy	0.26	0.01	42	0.44	0.04	14	0.85	0.04	4	0.48	
		dry	0.40	0.10	44	0.68	0.03	44	0.45	0.04	26	0.44	
Mn ppm	< 0.41	rainy	0.44	0.01	4	0.14	0.01	5	0.04	0.00	40	0.10	
		dry	0.05	0.00	38	0.10	0.00	4	0.04	0.00	11		
Fe ppm		rainy	4.44	0.14		4.79	0.14		4.17	0.42			
		dry	4.04	0.14		2.07	0.00		2.87	4.14			
Liver (0-8 mo)[d]													
Fe ppm	<100	rainy	364	40.0	18	419	84.4	4	414	44.1	14	364	
		dry	519	77.0	29	484	59.4	0	291	44.9	17	409	
Cu ppm	< 44	rainy	44.0	7.76	88	35.4	0.04	94	94.4	15.4	44	62.0	
		dry	40.4	10.4	44	409.3	20.4	44	425.1	14.0	23	59.4	
Mn ppm	< 4	rainy	4.69	0.40	40	44.44	1.04	0	11.44	4.56	0	40.4	
		dry	11.14	0.00	32	14.96	1.30	0	0.44	0.20	3	40.1	
Zn ppm	< 84	rainy	84.0	4.44	41	94.4	4.41	14	82.4	4.04	56	88.5	
		dry	84.4	4.44	74	100.4	10.4	21	94.0	4.58	27	94.4	
Mo ppm	< 0.05	rainy	0.25	0.04	8	0.44	0.04	0	0.10	0.04	4	0.21	
		dry	0.14	0.04	36	0.14	0.02	29	0.04	0.00	67		
Mn ppm	> 4	rainy	0.04	0.14		0.36	0.00		0.40	0.08			
		dry	0.03	0.00		0.05	0.01		1.01	0.00			
Se ppm	< 0.44	rainy	—	—	—			—					
		dry	0.00	0.14	0	1.09	0.14	0	1.01	0.06	0		

[a] McDowell et al. (1984).

[b] Means based on the following number of samples: Serum 46 (8 rainy, 8 dry) for San Jorge farm; 44 (8 rainy, 8 dry) for Don Benito and 46 (8 rainy, 8 dry) for San Francisco. Liver 17 (4 rainy, 4 dry) for San Jorge farm; 15 (4 rainy, 4 dry) for Don Benito and 18 (5 rainy, 4 dry) for San Francisco.

[c] Standard error of means.

[d] Means between seasons in a column with different superscripts differ (P<0.05).

TABLE 13 BLOOD SERUM AND LIVER MICROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND ANIMAL CLASS.

Variable	Critical level[a]	Season	Ewes			Lambs			Yearlings			Overall	
			Mean[b]	S.E.[c]	% Def.	Mean	S.E.	% Def.	Mean	S.E.	% Def.	Mean	% Def.
Serum													
Cu, ppm	< 0.1	rainy	0.82	0.06	19	0.10	0.06	11	1.85	0.01	11	1.12	
		dry	1.11	1.00	0	1.99	0.01	0	1.13	0.04	1	1.08	
Zn, ppm	< 0.1	rainy	0.00	0.04	11	0.10	0.01	1	0.69	0.01	11	0.26	
		dry	0.10	1.01	11	0.05	1.10	11	0.46	0.01	11	0.20	
Mo, ppm	< 0.01	rainy	0.11	0.01	10	0.10	0.01	1	0.04	0.01	10	0.05	
		dry	0.07	0.01	10	0.06	0.00	11	0.00	0.00	7	0.04	
Fe, ppm		rainy	1.17	0.13	0	1.90	0.10	0	1.21	0.17		1.41	
		dry	1.81	0.10	7	1.86	0.19	0	1.01	0.09		1.79	
Liver (0.6 basis)													
Fe, ppm	<100	rainy	141	17.6	8	111	80.7	01	110	70.8	11	143	
		dry	101	20.5	20	111	211	0	100	12.1	11	119	
Cu, ppm	< 71	rainy	56.1	11.1	60	11.2	0.01	100	90.1	12.6	58	01.0	
		dry	80.7	18.9	60	91.9	11.9	11	101.1	10.1	49	91.1	
Mn, ppm	< 6	rainy	10.35	0.51	1	1.96	1.31	20	11.1	0.96	0	10.1	
		dry	9.10	0.71	11	9.12	1.01	11	10.10	1.51	1	10.3	
Mn, ppm	< 84	rainy	01.6	1.51	11	76.0	11.2	01	101.0	1.91	28	86.1	
		dry	11.5	0.79	61	116.3	26.2	31	91.3	1.61	19	91.1	
Mo, ppm	< 0.06	rainy	0.26	0.01	0	0.13	0.04	0	0.18	0.01	0	0.19	
		dry	0.00	0.01	11	0.06	0.01	50	0.00	0.01	15	0.03	
Mo, ppm	> 4	rainy	0.51	0.06		0.05	0.11		0.19	0.04			
		dry	0.04	0.00		0.01	0.00		0.01	0.00			
Se ppm	< 0.25	rainy	—	—		—	—		—				
		dry	0.01	0.00		0.07	0.26		1.04	0.01			

[a] McDowell et al. (1984)

[b] Means based on the following number of samples: serum 11, 11 (rainy, dry) for ewes; 11, 11 (rainy, dry) for lambs and 15, 15 (rainy, dry) for yearlings; liver 11, 30 (rainy, dry) for ewes, 7, 0 (rainy, dry) for lambs and 10, 40 (rainy, dry) for yearlings.

[c] Standard error of means.

[d] Means between seasons in a column with different superscripts differ (P<0.01).

selenium and zinc tended to be higher during the rainy season, and copper higher during the dry season, but none was affected (P>.05) by season.

The percentage of serum samples deficient in copper, according to the value of .6 ppm (McDowell et al., 1984) was 18% during the rainy season and 0% during the dry season. Among animal classes, the deficiencies in copper were 19% for ewes, 24% for lambs and 14% for yearlings during the rainy season. Forage copper concentrations were shown to be highly deficient, especially during the dry season (94%). Serum copper concentrations are often directly effected by dietary copper intakes (Rowlands, 1980). However, serum copper concentrations do not always reflect dietary copper levels and copper deficiency may occur when serum copper concentrations are high. As discussed by Underwood (1981), copper deficiency is often caused by molybdenum and sulfur, which interfere with the utilization of copper by the animal, but which may induce either low or high plasma concentrations. It has been observed that low blood copper levels are associated with a reduced microbial activity of the phagocytes in the peripheral blood in sheep and cattle and this is possibly due to a reduction in the intracellular activity of the enzyme superoxide dismutase (Grace, 1988).

Based on a critical level of .03 ppm for selenium (McDowell et al , 1984), only 15 and 18% of the samples were considered deficient for rainy and dry seasons, respectively. There was no agreement with the percentage

deficiency found in the forage (43 and 69%) for this element.

Incidence of serum samples below the critical level of .6 ppm of zinc (McDowell et al., 1984) was 14 and 27% for rainy and dry seasons. Among animal classes, deficiencies were ewes, 11 and 21, lambs, 5 and 22; yearlings 23 and 33% for rainy and dry seasons, respectively. Because signs of zinc deficiency are nonspecific, poor zinc status should be considered in cases of unexplained reproductive problems in the ewe (Apgar and Fitzgerald, 1985). Serum zinc concentrations are a reasonable criterion to determine the status of the animal, however, values are particularly susceptible to stress of the animal during sampling and can fluctuate rapidly (Underwood, 1981).

Iron deficiency anemias are of the hypochromic microcytic type and it has been emphasized (Underwood, 1981) that an uncomplicated iron deficiency has not been observed in cattle or sheep under normal grazing conditions

Liver. Results of liver biopsy mineral concentrations as related to farm and season are presented in table 12, and as related to animal class and season are in table 13. Summary of analysis of variance of liver minerals is shown in appendix B table 32.

There were no significant farm by animal class interactions ($P>.05$) for any of the liver biopsy minerals considering seasons separately. Cobalt and molybdenum were higher ($P<.05$) during the rainy season.

Using the upper limit of the critical value of 75 ppm suggested for copper by McDowell et al. (1984), the percentage of liver samples deficient for this microelement were 72 for the rainy season and 51% for the dry season. However, if we use 25 ppm, which is the lower limit of the range (25-75 ppm) given by McDowell et al. (1984), the incidence of deficiencies would be 30% for the rainy season and 20% for the dry season. We can take the upper limit as the marginal level for deficiency and the lower limit as deficient. Among farms, the percentage of marginal copper deficiencies were San Jorge, 82 and 74; Don Benito, 93 and 57; San Francisco, 44 and 23% for rainy and dry seasons, respectively. Among animal classes the percent marginal copper deficiencies were ewes, 80 and 60; lambs, 100 and 33; yearlings, 50 and 49%. Undoubtedly, copper is marginal at best in a high proportion (59%) under the present conditions and special attention must therefore be given to this microelement in the formulation of mineral supplements especially in San Jorge and Don Benito.

Although the best criterion of copper status is copper content of liver, blood tests are widely used in practice (CMN, 1973). In this study soil, forage, serum and liver analyses indicated 14, 75, 8 and 59% copper deficiency, respectively. Forage appeared to aid in the diagnosis of copper deficiencies in sheep. Blood did not, but as reported by CMN (1973), if values in liver of yearlings fall

below about 25 ppa, copper concentrations in blood serum start to decrease.

For zinc, the percent liver samples below the critical level of 84 ppm suggested by McDowell et al. (1984) was 42 for the rainy season and 45% for the dry season. Among farms, deficiencies were San Jorge, 53 and 74; Don Benito, 13 and 21; San Francisco, 58 and 27% for rainy and dry seasons, respectively. There is no "best" analysis to determine zinc status in the animal (McDowell, 1985). In this study overall zinc deficiency in forages was 38%: on this basis forage appeared to aid in the diagnosis of zinc status in sheep.

Liver biopsy samples were not analyzed for selenium during the rainy season. The deficiency of selenium according to the critical value of .25 ppm (McDowell et al.,1984), was 0% for the dry season. This is in disagreement with McDowell et al. (1989) that serum and liver selenium concentrations provide good indicators of dietary selenium status in cattle. The deficiencies for selenium shown in this study were 100, 58, 18 and 0% for soil, forage, serum and liver, respectively. These data are similar to the data of Valdes et al. (1988). It can be concluded that, based on results of liver analyses and of the low percentage of deficient serum samples, selenium status of the sheep appeared to be adequate under present conditions. Forage levels, although marginally deficient, appeared to underestimate the selenium status of the animal.

There were no deficient samples for cobalt during the rainy season, according to the .05 ppm level (McDowell et al., 1984). However, 55% deficiency was found during the dry season. This deficiency appeared to be localized on the San Francisco farm, which had 87% of the samples deficient for cobalt. Among animal classes all three had similar deficiencies (55%) during the dry season. Overall deficiency of this element was 21% in liver and 87% in forage, which did not appear to accurately reflect the concentrations in liver.

The deficiency for liver manganese was 6% during the rainy season and 15% during the dry season according to the critical level of 6 ppm suggested by McDowell et al. (1984). The deficiency appeared to be localized only to San Jorge during both seasons. Among animal classes, ewes were 13% deficient, lambs, 31 and yearlings, 6%. Only 1% of the forage samples were deficient in manganese.

Liver iron means for the three farms were higher than the proposed critical level of 180 ppm (McDowell et al, 1984). However, 14% of samples of this element were low during the rainy season and 19% during the dry season. Liver iron concentrations suggested that most of the animals had adequate intake of iron. None of the soil samples, and only 1% of the forage samples were deficient for this micronutrient.

Evaluation of liver samples for molybdenum showed that none of the samples were above the suggested toxic level of

4 ppm (McDowell et al., 1984). Molybdenum has been shown to be an essential component of certain ruminant enzyme systems, but it can be toxic if it blocks copper use in the body (McDowell et al., 1983).

Correlation Coefficients of Minerals

Blood serum and liver mineral correlation coefficients as related to season are presented in appendix 8 table 29.

Correlation coefficients ($P<.05$, $r > |.050|$) between serum microelements and liver microelements during the rainy season were as follows: serum copper-liver copper (r=.86); serum copper-liver cobalt (r=-.75), liver cobalt-serum calcium (r=-.70). During the dry season the correlation coefficients were: serum zinc-liver iron (r=.90); serum iron-liver manganese (r=-.91); serum iron-liver cobalt (r=-.91); serum selenium-liver selenium (r=.84); liver copper-serum magnesium (r=-.80); liver cobalt-serum magnesium (r=.80), liver molybdenum-serum calcium (r=-.86). In general, the only positive correlations between serum and liver microelements were found for copper (rainy season), selenium (dry season) and serum zinc-liver iron (dry season).

Summary and Conclusions

A study was conducted to determine the mineral status of grazing sheep in three farms located on the paramo

region of the Cordillera Oriental in Colombia and to compare animal classes (pregnant-lactating ewes, lambs and yearlings). Soil, forage, blood and liver samples were taken at the end of the rainy season (May-June, 1987) and the middle to end of the dry season (February, 1988).

Season affected (P<.05) soil zinc and forage cobalt, copper, manganese, and molybdenum concentrations. Soil micromineral concentrations suggestingoverall (both rainy and dry seasons) deficiencies were selenium (100%), boron (83%), and manganese (54%). Forage microelements with the highest overall deficiencies were cobalt (87%) and copper (75%); copper was 94% deficient during the dry season. None of the values for molybdenum were above the toxic limit of 6 ppm for sheep, and the copper:molybdenum ratio was of at least 4:1. Iron and mangenese were in excess of the requirements for sheep but were below the maximum tolerable levels.

Blood serum analyses showed only small deficiencies; liver showed overall deficiencies for copper (59%) and zinc (44%), and for cobalt (55%) during the dry season. No diferences (P>.05) were found among animal classes for any of the plasma and liver microelements in both seasons. Ewes were more deficient in liver zinc (58%) and liver copper (71%); yearlings were more deficient in liver cobalt; and lambs were about as deficient in liver copper (68%) as ewes.

Based primarily on liver analysis it was concluded that copper, zinc and cobalt were the most deficient

microminerals. These elements plus selenium should be present continually in all supplementation programs in the paramo.

There was a lack of direct relationship between soil and plant micromineral concentrations. Mineral problems in livestock can be predicted by forage and tissue analyses.

CHAPTER VI
MINERAL CONCENTRATIONS IN LEAVES AND STEMS OF VARIOUS FORAGES OF THE COLOMBIAN PARAMO

Introduction

It is generally accepted that the nutritive value of a forage, measured as crude protein concentration and organic matter digestibility (IVOMD) is greater in the leaves than in the dead leaves or stems (Pitman and Holt, 1983). Analysis of total above-ground herbage often leads to an underestimation of the nutritional potential of forages since the animal selectively grazes parts of the plant which have greater protein concentration and higher digestibility (Arnold et al., 1966). Nutrient concentrations in different parts of the plant may vary greatly depending upon forage species, the rate of nutrient absorption and movement of nutrients within the plant (Loneragan, 1975).

Of the total mineral concentrations in soils, only a fraction is taken up by plants (Lindsay, 1972). However, little relationship has been reported between soil chemistry and mineral composition of native vegetation and farm crops (Reid and Horvath, 1980).

The purpose of this study was to determine the mineral concentration of the leaves and stems in forages of the paramo and to relate soil chemistry and the mineral composition of the same forages.

Materials and Methods

Soil and forage samples were collected from three sheep farms in the Cordillera Oriental of the paramo of Colombia. Sampling periods corresponded to the end of the rainy season (May-June, 1987) and the middle to end of the dry season (February, 1988).

A total of 113 composite soil and 131 composite forage samples were obtained. Each composite soil sample for each farm came from 8-12 samples. A soil sampling technique described by Bahia (1978) was used. Soil samples were analyzed by standard methods in the Laboratorio Nacional de Suelos of ICA in Bogota for organic matter, pH, aluminum, calcium, magnesium, phosphorus, potassium, sodium, boron, copper, iron, manganese and zinc. Minerals were extracted from the soil samples with a double acid extracting solution (.025N H_2SO_4 and .05N HCl). Soil mineral concentrations were determined by atomic absorption spectrophotometry (Perkin-Elmer, 1980).

Based on texture, the soil in the upper part (above 3,000 m) of San Jorge is classified as loamy (about 50%) or silt loam (about 50%); in the lower part (below 3,000 m)

about 40% of the soil is clay, 40% between clay loam and sandy clay loam, and the rest is sandy clay, loam, and sandy loam. In Don Benito the predominant soil is loamy, and in San Francisco is either loamy or silt loam. Each composite forage sample came from 20-25 samples of the same forage species predominating and most frequently grazed by sheep in the different areas of the farm. The forage species collected were vernalgrass (A. odoratum), a native cultivar of velvetgrass (H. lanatus L), an imported cultivar of velvetgrass (H. lanatus beeyn), kikuyugrass (P. clandestinum), white clover (T. repens), tall fescue (F. arundinacea), and orchardgrass (D. glomerata). Appendix B table 21 shows the detailed number of soil and forage species samples; proper identification of paddocks and of forage species is in appendix C. Samples were collected in plastic bags and kept refrigerated at 5° C until further processing. Samples were then hand separated by species and within each species they were further separated into two fractions; stems and leaves. The fractions were not weighed to get the percent composition of the canopy. In this study, then, only the absolute values for each fraction were obtained. Forage samples were processed and analyzed for mineral content according to methods described by Fick et al. (1979). Forage calcium, potassium, magnesium, sodium, iron, copper, manganese and zinc were determined by atomic absorption spectrophotometry using a Perkin-Elmer AAS 5000 (Perkin-Elmer, 1980). An atomic absorption

spectrophotometer equipped with a graphite furnace and Zeeman correction (Perkin-Elmer model 3030) was used to determine forage cobalt and molybdenum. Phosphorus was determined by a colorimetric method described by Harris and Popat (1954) and included by Fick et al. (1979). Selenium was carried out using a fluorometric technique described by Whetter and Ullrey (1979). For nitrogen analysis forage samples were digested using a modification of the aluminum block digestion procedure of Gallaher et al. (1975). IVOMD was performed by a modification of the two-stage technique (Moore and Mott, 1974).

Data were analyzed by the use of the Statistical Analysis System (SAS Institute, 1985). Soil and forage were analyzed as a split-plot design, with farm as the main plot and season as the subplot. For forage, plant part was considered as the subplot. However, the analysis of the forage data did not use species as a variable. Significance level was limited to .05 in all statistical analysis. Since the data were unbalanced, hypothesis testing was based on the Type IV Sum of Squares. Correlation coefficients between soil and forage minerals were estimated.

Results and Discussion

Plant Fractions-Macrominerals, Crude Protein, and IVOMD

Forage macromineral and crude protein concentrations and IVOMD as related to season and plant part are presented

in table 14. Summary of analysis of variance is presented in appendix B table 33.

Leaves had higher (P<.05) concentrations of the following nutrients: calcium, magnesium and crude protein during both seasons; phosphorus, potassium and IVOMD only during the dry season. Sodium was the only element with no difference (P>.05) between the two fractions during both seasons. The overall means showed that leaves were higher (P<.05) than stems for calcium, phosphorus, magnesium, potassium, crude protein and IVOMD. Within stems all nutrients had lower values during the dry season and within leaves all nutrients, except calcium, had lower values during the dry season.

The overall percentage of leaf calcium was more than twice that of stem, and the percentage of deficiencies were more drastic in stems (83 and 94%) than in leaves (18 and 8%) for rainy and dry seasons, respectively. Working with temperate grasses in Colombia, Laredo and Anzola (1986) reported a value of .31% in leaves and .12% in stems, values which agree with the present study.

Although significant (P<.05), the value of phosphorus in the leaves (.21%) was not much higher than in the stems (.19%); the percent deficiencies for the stems were 26 and 76% and for the leaves, 6 and 48% for rainy and dry seasons, respectively. Magnesium was found to be a highly deficient element in this study. Percentage of magnesium deficiencies were 78 and 94% for the stems and 23 and 59% for the leaves

TABLE 14. FORAGE MACROMINERAL, CRUDE PROTEIN AND IVOMD CONCENTRATIONS AS RELATED TO SEASON AND PLANT PART (DRY BASIS).

Variable	Critical level	Season	Stems			Leaves			Overall	
			Mean[a]	SE[b]	% Def	Mean	SE	Def	Part	Mean
Ca %	< 0.2[c]	rainy	0.18[f]	0.03	63	0.37[g]	0.04	10	stems	0.18[h]
		dry	0.11[f]	0.01	94	0.40[g]	0.00	0	leaves	0.38[h]
P %	< 0.16[c]	rainy	0.26	0.01	26	0.27	0.01	6	stems	0.19[h]
		dry	0.11[f]	0.01	76	0.18[g]	0.01	40	leaves	0.21[h]
Mg %	< 0.12[c]	rainy	0.12[f]	0.02	70	0.17[g]	0.01	21	stems	0.08[h]
		dry	0.07[f]	0.00	94	0.12[g]	0.01	58	leaves	0.14[h]
K, %	< 0.5[c]	rainy	2.72[f]	0.26	14	2.09	0.10	7	stems	1.52[h]
		dry	1.10[f]	0.09	12	1.62[g]	0.00	5	leaves	
Na %	< 0.05[c]	rainy	0.04	0.00	93	0.04	0.00	00	stems	
		dry	0.01	0.01	96	0.04	0.00	04	leaves	
CP %	< 7[d]	rainy	11.1[f]	0.65	26	18.0[g]	0.66	0	stems	
		dry	6.0[f]	0.38	67	14.1[g]	0.64	0	leaves	
IVOMD %		rainy	61.5[f]	2.02		68.1[g]	1.46		stems	5
		dry	51.8[f]	1.11		60.2[g]	0.99		leaves	64

[a] Means based on the following number of samples: 50 49 (rainy dry) for stems; 45 84 (rainy dry) for leaves

[b] Standard error of mean

[c] NRC (1985)

[d] Minson and Milford (1967)

[e,f] Means between plant parts in a row with different superscripts differ ($P<0.05$)

[g,h] Means between plant parts in a column with different superscripts differ ($P<.5$

during rainy and dry seasons, respectively. These data disagree with that of Montalvo et al. (1987) who found lower magnesium concentrations in leaves than stems. For practical purposes, animals grazing either one of the two fractions would not meet their requirements for magnesium.

For potassium, most of the samples had higher concentrations than the reported requirements; leaves had higher ($P<.05$) potassium concentrations than stems, but the percent deficiency in the stems was quite low (13%). There was no difference in sodium concentrations for the two fractions; both parts were highly deficient for this element during both seasons.

Although there was a difference ($P<.05$) in the concentration of crude protein between the two fractions, stems provided higher protein than the requirements during the rainy season but failed to do so during the dry season. Percent deficiency for stems was 26 and 67 and for leaves 8 and 9 during the rainy and dry seasons, respectively. A similar trend occurred with the IVOMD values between the two fractions. This could mean that the forages under this study are of good quality and provide adequate protein for the most of the year.

Plant Fractions-Microminerals

Forage micromineral concentrations as related to season and plant part are presented in table 15. Summary of analysis of variance is presented in appendix B table 34.

TABLE 15. FORAGE MICROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND PLANT PART (DRY BASIS).

Variable	Critical level	Season	Stems			Leaves			Plant part
			Mean[a]	S E[b]	% Rel	Mean	S E	% Rel	
Fe ppm	<30[c]	rainy	88 5	7 09	18	85 9	7 43	7	stems
		dry	182 8[1]	7 43	9	143 7[m]	18 9	9	leaves
Cu ppm	<10[d]	rainy	8 85	8 55	71	8 77	8 39	36	stems
		dry	2 67	8 24	96	3 21	8 21	93	leaves
Mn ppm	<40[c]	rainy	218[j]	11 4	18	181[n]	18 7	2	stems
		dry	225[k]	11 7	8	328[n]	21 8	6	leaves
Zn ppm	<30[c]	rainy	26 8[o]	1 50	36	28 3[p]	8 82	32	stems
		dry	19 8	1 35	58	18 8	8 88	53	leaves
Co ppm	< 8 1[c]	rainy	8 08	8 01	88	8 87	8 01	74	stems
		dry	8 05	8 01	96	8 85	8 01	87	leaves
Mo ppm	> 8[d]	rainy	8 47[l]	8 07	-	1 22[q]	8 18	-	stems
		dry	8 55	8 17	-	8 85	8 88	-	leaves
Se ppm	< 8 1[c]	rainy	8 09	8 01	64	8 11	8 01	59	stems
		dry	8 08	8 01	82	8 88	8 01	70	leaves

[a] Means based on the following number of samples: 50 (49 rainy 1 dry) for stems; 65 (64 rainy 1 dry) for leaves

[b] Standard error of means

[c] NRC (1985)

[d] Underwood et al (1988)

[e] [l] Means between plant parts (= row with different superscripts differ (P < .05

[f] [k] Means between plant parts (= column with different superscripts differ (P

Leaves had higher (P<.05) concentrations of molybdenum during the rainy season, higher concentrations of iron, and manganese during the dry season, but were lower (P<.05) than stems in zinc concentration during the rainy season. The overall means showed that leaves were only higher (P<.05) than stems in iron and molybdenum concentrations.

Within stems, iron, manganese, and molybdenum had higher values during the dry season; copper, zinc, cobalt, and selenium were higher during the rainy season.

Montalvo et al. (1987) and Laredo and Anzola (1986) also found higher concentrations of iron in leaves than stems. Percent deficiency of this element, according to the 20 ppm critical value (NRC, 1985), was only 4% for leaves and 10% for stems. Concentration of iron in forages suggested that sheep in the paramo do not need supplemental iron in the diet.

Molybdenum was higher (P<.05) in leaves than stems, but none of the individual values were higher than the 6 ppm suggested by NRC (1985) as the toxic limit.

Cobalt was equally highly deficient comparing the two fractions. According to the .1 ppm level (NRC, 1985), leaves were 85% deficient and stems 92% deficient. Along with copper, these elements proved to be the most deficient in the forages of this study, and both were potentially limiting grazing sheep productivity in the area.

For copper the deficiencies were 65% in the leaves and 82% in the stems. According to these results, copper should be provided to sheep in the mineral mix.

Laredo and Martinez (1984) reported that both zinc and copper were the microelements most affecting production and reproduction of beef cattle in Colombia. Zinc presented 46% deficiency in stems and 42% in leaves, according to the 30 ppm value (NRC, 1985). Montalvo et al. (1987) found much greater zinc levels in the stems than in the leaves. Selenium was highly deficient especially in stems during the dry season (92% deficiency) using the critical level of .1 ppm (NRC, 1985). In general, stems were 77% selenium deficient and leaves 65%.

Manganese was consistently higher in both fractions than the recommended value of 40 ppm (NRC, 1985). It is not advisable to supplement sheep with manganese as it can interfere with the utilization of other minerals.

Forage Species

Minerals, crude protein and IVOMD concentrations of forage species collected during the rainy and dry seasons, presented with overall species deficiencies are in tables 16 (macrominerals) and 17 (microminerals); presented with individual species deficiencies are in appendix B tables 35 (macrominerals) and 36 (microminerals). Concentrations tended to differ, but the differences were not statistically analyzed, because of the uneven occurrence of some of the species which produced a large number of empty cells.

TABLE 16 FORAGE MACROMINERAL, CRUDE PROTEIN AND IVOMD CONCENTRATIONS BY SPECIES (DRY BASIS).

Variable	Critical level	Season	A. obtectus		B. lanatus L.		H. lanatus banyn		P. clandestinum		T. repens		P. stoloniferum		G. glomerata		Overall	
			Mean[a]	SE[b]	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	% Def
Ca %	< 0.2[c]	rainy	0.22	0.02	0.21	0.02	0.22	0.02	0.32	0.02	2.49	0.12	0.67	0.02	0.22	0.04	0.37	22
		dry	0.26	0.02	0.28	0.02	0.30	0.02	0.27	0.02	1.67		-		0.28	0.00	0.21	22
P %	< 0.2[c]	rainy	1.78	0.15	2.75	0.16	3.00	0.16	2.02	0.16	1.71	0.20	4.02	0.56	2.08	0.23	2.75	0
		dry	1.00	0.08	1.00	0.12	2.00	0.22	1.00	0.16	2.23			-	2.42	0.22	2.40	1
Mg %	< 0.12[c]	rainy	0.12	0.00	0.26	0.01	0.12	0.01	0.22	0.02	0.34	0.00	0.21	0.00	0.12	0.01	0.16	11
		dry	0.00	0.00	0.15	0.01	0.00	0.01	0.23	0.02	0.28			-	0.10	0.01	0.21	7
Na %	< 0.02[c]	rainy	0.02	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.12	0.02	0.00	0.00	0.02	0.00	0.02	93
		dry	0.03	0.00	0.00	0.01	0.00	0.02	0.02	0.00	0.00	-	-		0.21	0.02	0.00	94
K %	< 0.36[c]	rainy	0.21	0.01	0.26	0.01	0.38	0.01	0.26	0.02	0.38	0.02	0.82	0.01	0.25	0.02	0.22	3
		dry	0.12	0.00	0.16	0.02	0.12	0.02	0.17	0.02	0.22				0.12	0.00	0.25	61
CP %	< 7[d]	rainy	18.9	2.20	22.0	0.02	20.2	0.02	25.5	1.00	29.6	1.22	12.8	2.0	21.2	0.00	18.4	1
		dry	9.5	0.48	14.9	0.90	20.2	0.90	9.4	0.28	21.0	-	-	-	20.2	1.22	12.3	11
IVOMD %		rainy	62.2	1.01	20.2	1.22	72.9	1.22	62.9	2.22	20.2	6.2	70.2	2.0	78.5	2.59	66.2	
		dry	51.0	1.02	01.7	1.29	56.2	2.22	52.2	2.78	60.2				69.8		56.2	

[a] Means based on the following number of samples: 23, 20 (rainy, dry) for A. obtectus; 26, 29 (rainy, dry) for B. lanatus L.; 10, 0 (rainy, dry) for H. lanatus banyn; 10, 2 (rainy, dry) for P. clandestinum; 8, 3 (rainy, dry) for T. repens; 2, 0 (rainy, dry) for P. stoloniferum; and 2, 2 (rainy, dry) for G. glomerata.

[b] Standard error of means.

[c] NRC (1982).

[d] Minson and Milford (1967).

TABLE 17. FORAGE MICROMINERAL CONCENTRATION BY SPECIES (DRY BASIS)

Variable	Critical level		Season	A. oderatum Mean[a]	A. oderatum S.E.[b]	H. lanatus L. Mean	H. lanatus L. S.E.	H. lanatus hairy P. clandestinum Mean	H. lanatus hairy P. clandestinum S.E.	T. repens Mean	T. repens S.E.	P. arundinacea Mean	P. arundinacea S.E.	S. glomerata Mean	S. glomerata S.E.	Overall Mean	Overall % Def
Cu	ppm	< 8[e]	rainy	8.05	0.57	7.88	0.88	7.88	0.00	8.91	1.09	10.1	1.11	9.27	1.27	7.38	0.87	7.18	57
			dry	8.05	0.87	8.38	0.88	3.38	0.87	8.88	0.85	8.8				6.77	0.17	3.07	04
Co	ppm	< 0.1[c]	rainy	0.05	0.00	0.08	0.03	0.03	0.00	0.16	9.02	0.10	0.05	0.06	0.02	0.04			
			dry	0.08	0.00	0.05	0.06	0.01	0.00	0.12	9.01	0.08							
Fe	ppm	< 30[c]	rainy	188	19.1	81	7.61	96	18.8	57	10.9	94	17.1						
			dry	158	10.7	119	10.8	158	27.5	83	12.8	107							
Mn,	ppm	< 20[c]	rainy	281	30.8	818	10.1	236	15.5	126	18.8	189							
			dry	368	88.8	843	23.8	385	87.6	261	89.6	139							
Mo	ppm	> 5[d]	rainy	1.38	0.15	0.58	0.18	1.18	0.83	0.87	0.38	1.42	0.0						
			dry	0.68	0.11	0.38	0.03	0.88	0.82	0.18	0.01	0.29							
Se	ppm	< 0.1[c]	rainy	0.18	0.03	0.18	0.03	0.08	0.01	0.18	0.08	0.14							
			dry	0.87	0.08	0.08	0.03	0.15	0.01	0.28	0.05	0.18				0.18	0.7	6	
Zn	ppm	< 20[c]	rainy	21.8	1.18	21.9	1.81	20.8	1.18	35.8	4.51	38				1.84	1.9	28	
			dry	88.8	1.18	15.8	1.48	87.3	4.98	22.9	4.88	14				1.8	21.7	88	

[a] Means based on the following number of samples: 18 (rainy, dry) for A. oderatum; 10 (rainy, dry) for H. lanatus; 10, 5 (rainy, dry) for P. clandestinum; 8, 3 (rainy, dry) for T. repens; 2 (rainy) for P. arundinacea; 4, 2 (rainy, dry) for S. glomerata.

[b] Standard error of means.

[c] NRC (1980).

[d] McDowell et al. (1984).

[e] Underlined values are deficient.

Because it may be of interest, means and standard errors of each species in a season, are presented.

There is a variety of forage species which have colonized the paramo, and for the purpose of this study they are considered native to the paramo. Among them, the most important for grazing sheep are Holcus lanatus L (velvetgrass), Anthoxanthum odoratum (vernalgrass), Lachemilla orbiculata (plegadera), and Trifolium repens (white clover) (Ferguson et al., 1987). Pennisetum clandestinum (kikuyugrass) is an aggressive species which grows well up to 2900-3000 m. Samples of this grass were only obtained in the lower part of the farm San Jorge. The reason two ecotypes of H. lanatus were included in this study was because of canopy structure differences between the two. The native ecotype, H. lanatus L, produces many erect, unbranched stems with few leaves; matures very early and is a prolific seed producer. In contrast the imported ecotype, H lanatus basyn, forms a denser canopy with more leaves, and is not a seed producer during a considerable time (Mack and Pastrana, 1987).

Among the introduced grasses of value to the paramo are Dactylis glomerata, Festuca arundinacea and Lolium perenne. They have the disadvantage of being easily overcome by the native species.

Mean calcium concentrations ranged from .24% in H. lanatus basyn to 1.53% in T. repens. According to the value of .2% as a critical level for sheep (NRC, 1985), H. lanatus

baeyn wee 27% deficient for calcium considering both seasons. For potessium, none of the species (except A. odoratum, with 2% deficiency) were defioient, according to the .5% ieval (NRC, 1985).

The loweet mean magneeium concentrations were found in A. odoratum (.09%), H. lanatus baeyn (.12%) and D. glomerata (.12%) and the highest was found in T. repens. The percent defioiency was 77, 62, 87 and 0%, reapectively. All epecies were highly deficient in eodium, according to the level of .09% (NRC, 1985). P. clandestinum was 100% deficient and T. repens 40%.

Mean phosphorus concentrations renged from .15% in A. odoratum to .41% in D. glomerata and F. arundinacea. The eame epecies ehowed e deficiency of 56, 0 and 0%, according te the .16% value for phoephorue euggested by NRC (1985).

For crude protein and IVOMD, epecies were different ee related to eeaeon. All epecies had higher veiues of protein and IVOMD during the reiny eeaeon. The overall mean protein concentration ranged from 11.4% for A. odoratum to 27.9% for T. repens, und IVOMD ranged from 52.3% for P. clandestinum to 73.7% for D. glomerata.

Among the microeiementa, high deficiency percenteges were found for copper, cobalt, eelenium and zinc. Mean copper concentration ranged from 3.24 ppm in A. odoratum to 9.27 ppm in F. arundinacea. Percent deficiancies were 93% for A. odoratum and 20% for T. repens, according to the critical value of 7 ppm (NRC, 1985).

H. lanatus hasyn and P. glomerata had the lowest mean values of cobalt (.03 ppm) and P. clandestinum (.14 ppm), the highest. The percent cobalt deficiency in P. clandestinum was 33%, and A. odoratum was 88% deficient. For selenium, the values ranged from .07 ppm (A. odoratum and P. arundinacea) to .16 ppm (P. clandestinum). According to the critical concentration of .1 ppm (NRC, 1985), A. odoratum was 72% deficient for this element.

H. lanatus L had a zinc mean value of 19.4 ppm which is below the critical value of 20 ppm suggested by NRC (1985). Percent deficiency for the element was 46%. None of the species had iron or mangenese mean values below the critical levels recommended by NRC (1985). However, P. clandestinum presented 20% deficiency for iron and 7% for mangeneses.

Excluding A. glomerata and F. arundinacea from overall comparisons, A. odoratum had the lowest values for potassium, magnesium, phosphorus, copper, selenium, and crude protein; T. repens had the highest values for calcium, potassium, magnesium, sodium, phosphorus, copper, molybdenum, zinc, crude protein and IVOMD.

Comparing the two ecotypes of H. lanatus, H. lanatus hasyn was higher than the native grass in potassium (2.62 vs 2.13%), sodium (0.4 vs 0.3%), phosphorus (.24 vs .21%), copper (6.23 vs 4.49 ppm), iron (116 vs 103 ppm), mangenese (268 vs 232 ppm), molybdenum (1.09 vs .64 ppm), selenium (.12 vs .10 ppm), zinc (22.8 vs 18.4 ppm), protein (19.5 vs 14.6 %) and IVOMD (68.7 vs 65.5 %). However, the

differences were not extreme enough to claim H. lanatus basyn (imported) to be a better ecotype. If production of DM/ha is higher in H. lanatus basyn, as reported by Laredo et al. (1989), then, this ecotype is of much greater value than the native ecotype for grazing sheep on the paramo.

With the exception of provided salt, sheep depend entirely on forages to meet their mineral requirements. However, as shown in this study, the predominant forage species of the paramo do not meet mineral requirements, therefore, mineral supplementation, apart from common salt, is needed in the area.

Soil-Plant Relationship

Results of correlation coefficients between soil and forage minerals as related to season are presented in table 18. Mineral concentration of a plant depends to some extent on the mineral concentration of the soil. However, soil properties and conditions markedly effect mineral uptake and utilization by plants (Wilkinson, 1972).

Correlation coefficients ($P<.05$, $r > |.50|$) between soil minerals and the corresponding forage minerals, during the rainy season, were as follows: calcium (r=.81), magnesium (r=.89), potassium (r=.71), zinc (r=.69). During the dry season, the correlation coefficients were calcium (r=.61), and magnesium (r=.58). Only calcium and magnesium had positive correlation coefficients ($P<.05$, $r > |.50|$) for both seasons of the 12 mineral elements evaluated. These results showed that only a few minerals have a high correlation

TABLE 18. CORRELATION COEFFICIENTS BETWEEN SOIL AND FORAGE MINERALS AS RELATED TO SEASON [a]

Variable	Season	No. [b]	[illegible]	Al	Ca	P	[illegible]	K	Na	Cu	Fe	Mn	Zn	O
Pasture														
Ca	rainy	- 44	56[a]	- 44[a]	01[**]	14	51[a]	11	48[a]	02	11	10	51[a]	41
	dry	- 29	41	- 14	61[a]	11	42	17	45[+]	48	- 04	45[+]	29	40
P	rainy	- 34	- 11	44[a]	11	46[+]	11	42	78	55[a]	75[**]	- 01	51[a]	10
	dry	- 40	19	41[a]	59[a]	11	27	19	32	17	- 18	11	14	54[a]
Mg	rainy	78[**]	56[a]	60[a]	01[**]	11	68[**]	30	01[**]	01	02	72[**]	11[**]	11
	dry	74[**]	61[a]	11	61[a]	44[+]	58[a]	44[a]	49[+]	59[a]	01	67[**]	47[+]	17
K	rainy	- 44[+]	- 21	11	08	29	10	71[**]	05	06[+]	08[a]	08	63[**]	07
	dry	46[+]	15	14	41[a]	14	30	14	39	21	11	35	29	11
Na	rainy	16	20	- 17	22	00	08	- 14	06	- 25	10	20	10	-
	dry	17	00	10	13	41	- 11	14	- 11	26	- 01	11	16	-
Cu	rainy	40	21	11	36	01	36	69[**]	24	05	26	36	41	-
	dry	11	- 01	10	14	11	28	01	07	10	11	11	1	-
Fe	rainy	12	- 25	25	- 29	06	- 14	- 50[+]	- 24	04	11	08[a]	30	04
	dry	64[**]	51[a]	08	12	56[a]	- 01[a]	- 36	- 47[+]	- 41[a]	- 10	- 41[a]	71[**]	1
Mn	rainy	40	67[**]	56[a]	- 41[**]	01	56[a]	41[+]	- 47[+]	05[a]	- 11[a]	- 46[+]	- 11	- 61[a]
	dry	30	- 08[**]	08[**]	40[+]	14	41	- 58[a]	46[+]	46[+]	41[+]	- 11	- 28	- 36
Zn	rainy	- 61[**]	28	11	54[a]	- 08	44[a]	41	51[a]	19	39	29	69[**]	28
	dry	31	- 44[+]	11	- 15	10	- 29	- 52[a]	- 10	- 30	29	- 26	14	21
Co	rainy	- 71[**]	54[a]	- 08[a]	72[**]	45[+]	05[**]	- 10	07[**]	01	- 16	58[**]	17	10
	dry	58[a]	43	08	63[a]	14	52[a]	66[a]	74[**]	54[a]	11	08[**]	75[a]	1
Mo	rainy	24	- 46[+]	01[a]	- 38	38	- 50[+]	01	- 41	- 04[+]	25	56[a]	15	
	dry	39	- 36	19	05	09[**]	- 19	- 21	- 21	- 07[+]	10	11	11	
Se	rainy	12	05	11	24	42	10	23	11	- 10	58[a]	11[a]	44[+]	14
	dry	10	21	10	21	08	14	14	11	14	01	41[a]	38	2
CP	rainy	80	- 40	38	10	14	- 11	41[+]	17	11	41	- 21	17	33
	dry	- 01	- 05	- 11	70	24	- 07	- 01	- 01	11	11	- 05	- 17	41

[a] Correlation coefficients based on 17 and 15 means for rainy and dry seasons respectively

[b] Organic Matter

[+] $P < 0.10$

[*] $P < 0.05$

[**] $P \leq 0.01$

between soil and forage values. Therefore, soil analyses are not of great importance when assessing mineral status of sheep in the paramo.

Correlation coefficients between soil organic matter and forage nutrients for the rainy season were magnesium (r=-.76), zinc (r=-.63), and cobalt (r=-.71). For the dry season, correlation coefficients for soil organic matter were magnesium (r=-.74), iron (r=.64), and cobalt (r=-.59). Correlation coefficients between soil pH and forage nutrients for the rainy season were calcium (r=.56), magnesium (r=.58), manganese (r=-.67), and cobalt (r=.54). For the dry season, correlation coefficients were magnesium (r=.61), iron (r=-.53), and manganese (r=-.68). Hodgson (1963) reported the effect of pH on mineral absorption by plants, which could be modified by plant species and by the amount and form of the element in the soil.

Summary and Conclusions

A study was conducted to determine the mineral composition of two plant fractions (leaves and stems) of several forage species in three sheep farms of the paramo in Colombia. The mineral composition of the forage species, and the relationship between soil chemistry and the mineral composition of the forages were also determined. Sampling periods corresponded to the end of the rainy season (May-June, 1987) and the middle and end of the dry season (February,

1988). Leaves were higher ($P<.05$) than stems in the following: calcium, phosphorus, magnesium, potassium, iron molybdenum, crude protein, and IVOMD. Overall percentage of deficiencies was as follows: calcium (88, 13), phosphorus (50, 27), magnesium (85, 41), potassium (13, 3), sodium (94, 96), iron (10, 4), copper (82, 65), manganese (7, 0), zinc (46, 42), cobalt (92, 85), selenium (77, 65), crude protein (45, 8%) for stems and leaves, respectively.

Based on analyses, mineral, crude protein and IVOMD concentrations of forage species, tended to differ. Soil-forage correlation coefficients of the same mineral for the rainy season were calcium ($r=.81$), magnesium ($r=.89$), potassium ($r=.71$), zinc ($r=.69$). For the dry season, correlations were calcium ($r=.61$) and magnesium ($r=.58$). Results indicated low correlation coefficients between soil and forage minerals, and that they are not of great value in assessing the mineral status of grazing sheep in the paramo.

CHAPTER VII
SUMMARY AND CONCLUSIONS

A study was conducted in three farms of the Cordillera Oriental on the paramo region of Colombia to determine the mineral status of grazing sheep by evaluating mineral concentrations in soil, plant, and animal tissues.

Sampling collections corresponded to the end of the rainy season (May-June, 1987) and the middle and of the dry season (February, 1988). Samples were collected from animals that were divided into three classes: lactating (or pregnant) ewes, lambs (1-4 months of age), and yearlings (10-14 months). A total of 113 composite soil, 131 composite forage, 207 blood serum, 192 whole blood, 148 rib bone biopsy and 113 liver biopsy samples were obtained for each of the sampling periods.

Soil samples were analyzed for organic matter, pH, aluminum, calcium, phosphorus, magnesium, potassium, sodium, iron, copper, manganese, zinc, selenium and boron. Forage samples were analyzed for the same minerals as in soil (except aluminum and boron) in addition to cobalt, molybdenum, crude protein and IVOMD. Blood samples were analyzed for calcium, phosphorus, magnesium, copper, zinc, selenium and iron. Bone was analyzed for calcium,

phosphorus, magnesium, and ash concentration. Liver was analyzed for iron, copper, manganese, zinc, cobalt, molybdenum and selenium. Whole blood samples were analyzed for hematocrit, hemoglobin, total leucocytes, neutrophils, lymphocytes, monocytes, eosinophils and basophils.

Season affected ($P<.05$) concentrations of soil calcium, which were higher in the dry season, and sodium and zinc, which had higher values during the rainy season. Overall incidence of forage deficient samples in decreasing order was as follows: selenium (100%), boron (83%), magnesium (70%), manganese (54%), potassium (52%), phosphorus (46%), calcium (24%), copper (14%), zinc (12%), and iron (7%). The three farms were characterized by their high organic matter (19%) and low pH value (5.0).

Season affected ($P<.05$) concentrations of forage manganese, which had higher values during the dry season, and of potassium, magnesium, phosphorus, cobalt, copper, molybdenum and crude protein which had lower values during the dry season. Overall incidence of deficient forage samples in decreasing order was as follows: sodium (93%), cobalt (87%), copper (75%), selenium (56%), magnesium (53%), zinc (36%), phosphorus (32%), calcium (17%), and crude protein (6%). None of the values for molybdenum were above the toxic limit of 6 ppm for sheep, and the copper:molybdenum ratio was of at least 4:1. Iron and manganese were in excess of the requirements but were below the maximum tolerable levels for sheep.

Plant fraction was a source of variation for forage minerals. Leaves had higher ($P<.05$) concentrations for calcium, phosphorus, magnesium, potassium, iron, molybdenum and crude protein. Based on analyses, mineral, crude protein and IVOMD concentrations among forage species tended to differ. A high percentage of species were deficient in magnesium, sodium, cobalt, copper, selenium and zinc for both seasons and in phosphorus in the dry season.

Among soil minerals and the corresponding forage minerals, only calcium and magnesium had positive correlation ($P<.05$, $r > |.50|$) coefficients for both seasons of the 12 mineral elements evaluated. Therefore, soil analyses are not of great importance when assessing mineral status of sheep in the paramo.

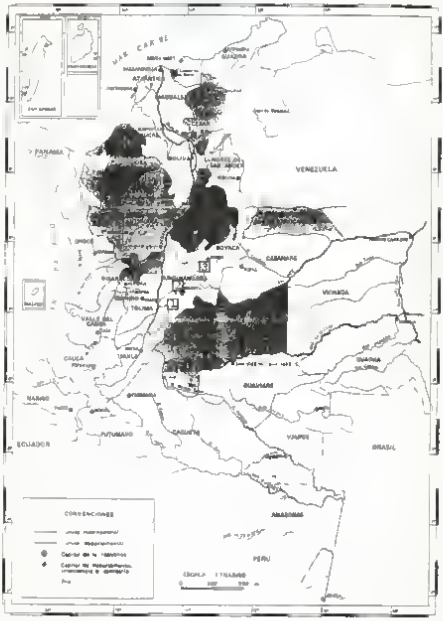
Season only had effect ($P<.05$) on the following animal tissues: serum phosphorus, and liver cobalt and molybdenum, which had lower concentrations during the dry season. Serum analyses showed an overall phosphorus deficiency in 59% of the samples, magnesium 38%, zinc 21%, selenium 16%, and copper 8%; calcium was 94% deficient during the dry season. Bone was 98% deficient in both calcium and phosphorus, with ash percentage being also very deficient (95%). Liver showed an overall copper deficiency of 59%, zinc 44%, and cobalt 55%, and selenium 41% during the dry season. Differences ($P<.05$) among animal classes were found in serum phosphorus in both seasons (lambs were higher in phosphorus), lambs were lower in serum magnesium during the

dry season, and bone ash during the rainy season. No differences ($F>.05$) were found among animal classes for any of the serum and liver microelements in both seasons. Ewes were more deficient in liver zinc (58%) and liver copper (71%); yearlings were more deficient in liver cobalt (40%); lambs were as deficient in liver copper (69%) as ewes.

In general, mineral elements among animal tissues did not correlate with each other. Considering only the minerals which were analyzed in the samples it can be concluded that the minerals most likely limiting sheep production in the paramo were calcium, phosphorus, magnesium, copper, zinc, and cobalt. Supplementation programs for sheep in the paramo should provide common salt, calcium, phosphorus, magnesium, copper, zinc, cobalt and selenium.

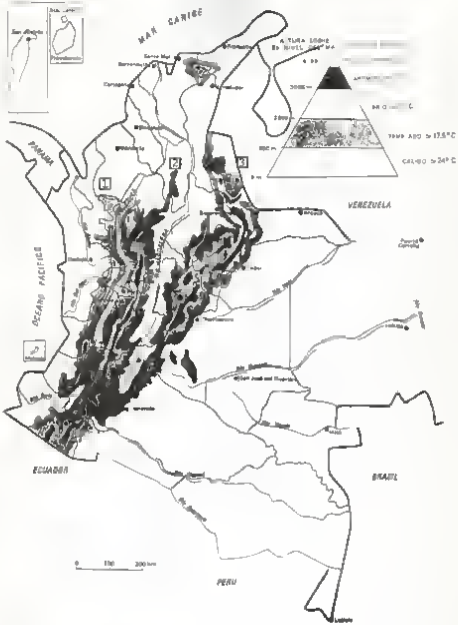
APPENDIX A

FIGURES



1 San Jorge
2 Don Benito
3 San Francisco

FIGURE 1- COLOMBIA, GEOGRAPHICAL LOCATION OF THE THREE SHEEP FARMS SURVEYED.



1 Cordillera Occidental
2 Cordillera Central
3 Cordillera Oriental

FIGURE 2. THE PARAMO REGION IN COLOMBIA.

APPENDIX B

TABLES

TABLE 18. DESCRIPTION OF FARMS

Description[a]	San Jorge	Don Benito	San Francisco
Name of owner:	ICA	Caja Agraria	Caja Agraria
Location of farm:			
Departamento	Cundinamarca	Cundinamarca	Boyaca
Municipio	Soacha	Zipaquira	Ventaquamada
Distance from Bogota (km)	30	50	110
Land use			
Total area (ha)	800	836	1100
Natural pasture (ha)	445	320	480
Improved pasture (ha)	60	80	80
Agronomic crops (ha)	80	70	110
Forest-shrubs (ha)	110	216	260
Non-usable land (ha)	105	150	160
Pastures			
Name of predominant forages:			
First	Holcus lanatus	Holcus lanatus	Holcus lanatus
Second	A.odoratus	A.odoratum	A.odoratum
Third	P.clandestinus	T.repens	P.clandestinum
Grazing system	rotational	rotational	rotational
Stocking rate (animals/ha)	3.4	2.2	3.6
Sheep			
Principal breeds	Criollo Romney	Blackface Criollo	Blackfece Romney
Total sheep	1710	872	2045
Rams	85	24	96
Ewes	605	320	720
Lasha	526	272	634
Yearlings	404	256	585
Lambing (%)	87	85	88
Mortality (%)	6	6	6
Breeding season	Aug-Sept	Nov-Dec	Dec-Jan
Lambing season	Jan-Feb	April-May	May-June
Weaning age (months)	4	4	4
Age female bred (months)	18	18	18

TABLE 19.--CONTINUED

Description[a]	San Jorge	Don Benito	San Francisco
Parasite control			
Internal	every month	3 times/yr	4 times/yr
External	once/yr	once/yr	once/yr
Mineral supplements[b]	yes	yes	yes

[a]Some data were derived from approximation in cases where exact data were not available.

[b]Mineral supplementation was not a continuous practice in any case.

TABLE 20. CLIMATE AND AVERAGE MONTHLY RAINFALL (mm)

Description	Farm		
	San Jorge	Don Benito	San Francisco
Type	Dry forest Lower montane	Wet forest Montane	Wet forest Montane
Average temperature (°C)	10	9	9
Average rainfall (mm)	640	1300	1300
Rainfall, 1987 (mm)			
January	13.8	21.3	
February	25.3	97.4	
March	35.4	52.0	
April	73.7	100.7	
May	120.0	217.2	
June	13.2	89.4	
July	77.0	125.2	
August	43.5	78.4	
September	42.7	96.1	
October	93.0	220.7	
November	43.7	87.8	
December	21.7	50.5	
January, 1988	31.8	16.5	

TABLE 21. DETAILED NUMBER OF SOIL AND FORAGE COMPOSITE SAMPLES

Paddock #	Rainy season (1987) Soil	Forage	Species[a]	Rainy season (1987) Soil	Forage	Species
San Jorge						
1	4	4	1	4	4	1
2	4	4	2,3	4	4	2,3
3	4	9	2,3,4,5	4	8	1,2,3,4
4	4	7	2,3,4,6	4	6	1,2,3,6
5	4	4	1			
6				2	3	1,2
7				1	2	1,2
8				1	2	1,2
Totals	28	28		20	29	
Don Benito						
9	4	4	7			
10	4	4	2	3	3	1,2
11	4	4	7			
12	4	4	2			
13	3	4	1,4,6,7	4	5	6,7
14				3	3	1
15				4	4	1,2
Totals	19	20		14	15	
San Francisco						
16	4	4	2			
17	4	4	1	4	4	1
18	4	4	7			
19	4	4	7	4	4	7
20	4	3	6,7			
21				4	4	1,2
22				4	4	1
23				4	4	1
Totals	20	19		20	20	

[a]Species identification is in Appendix C.

TABLE 22. COMPOSITION OF THE MINERAL MIXTURES[a]

Compound	%	Element	
San Jorge[b]			
Common salt	50.0	Sodium chloride	50.0%
Steamed bonemeal	49.7	Calcium	14.4%
Cupric sulfate	.25	Phosphorus	6.0%
Potassium iodide	.005	Copper	.06%
Cobalt chloride	.003	Cobalt	7.0 ppm
Don Benito and San Francisco[c]			
Common salt	62.0	Sodium chloride	62.0%
Dicalcium phosphate	33.0	Calcium	10.0%
Zinc sulfate	1.7	Phosphorus	6.0%
Flowers of sulfur	1.0	Sulfur	1.0%
Cupric sulfate	.6	Copper	.15%
Potassium iodide	.015	Zinc	.5%
Cobalt chloride	.004	Iodine	100.0 ppm
Sodium selenite	.003	Selenium	14.0 ppm
		Cobalt	10.0 ppm

[a]Calculated consumption of mineral mixture: 12 g/head/day in San Jorge and 10 g/head/day in Don Benito and San Francisco.

[b]Mineral supplementation was available during breading and lactation and occasionally during the rest of the year.

[c]Mineral supplementation was available during most of the year.

TABLE 23. DETAILED NUMBER OF TISSUE SAMPLES

Animal class	Rainy season (1987)				Dry season (1988)			
	Serum	Blood	Bone	Liver	Serum	Blood	Bone	Liver
San Jorge								
Ewes	12	12	11	8	10	11	12	8
Lambs	12	13	7	3	12	13	12	6
Yearlings	12	10	8	6	12	12	9	9
Totals	36	35	26	17	34	36	33	23
Don Benito								
Ewes	13	12	11	8	6	4		
Lambs	9	10	7	4	6	5		
Yearlings	11	10	4	3	22	24	15	14
Totals	33	32	22	15	34	33	15	14
San Francisco								
Ewes	12	10	12	9	17	11	8	8
Lambs					9	4		
Yearlings	12	10	13	9	20	21	19	18
Totals	24	20	25	18	46	36	27	26

TABLE 24. SUMMARY OF ANALYSES OF VARIANCE OF SOIL ORGANIC MATTER, pH, AND MACROMINERALS--MEAN SQUARES BY SEASON

Response	Farm[a]	Paddock/farm	Residual
		Rainy season	
Organic matter	1495.51**	140.08	7.05
pH	.6272*	.2316	.0090
Aluminum	842202.17*	185294.14	4250.61
Calcium	2571258.49*	504613.84	10424.34
Magnesium	193431.01*	31442.20	784.87
Phosphorus	7774.58	3168.51	177.36
Potassium	11364.49	4631.40	742.66
Sodium	5769.74**	360.06	20.61
df[b]	2	12	44
		Dry season	
Organic matter	277.63	140.92	6.1174
pH	1.6800**	.1811	.0329
Aluminum	323635.24*	108049.92	15913.57
Calcium	1357359.20	646938.00	41548.64
Magnesium	50091.30	21191.18	1483.12
Phosphorus	706.94	699.91	82.14
Potassium	12400.31*	3912.66	349.19
Sodium	538.40*	174.21	52.48
df	2	13	38

[a]Test farm using paddock/farm as an error term.

[b]Represents degrees of freedom.

*P<0.10.

**P<0.05.

***P<0.01.

TABLE 25. SUMMARY OF ANALYSES OF VARIANCE OF FORAGE CRUDE PROTEIN, IVOMD AND MACROMINERALS--MEAN SQUARES BY SEASON

Response	Farm[a]	Paddock/farm	Residual
		Rainy season	
Calcium	.2381	.1083	.0640
Magnesium	.0261*	.0080	.0028
Phosphorus	.0472*	.0167	.0020
Potassium	5.9751*	1.7484	.3998
Sodium	.0011	.0007	.0009
Crude protein	80.3744*	28.4002	19.0156
IVOMD	1236.18**	77.0316	47.5852
df[b]	2	12	52
		Dry season	
Calcium	.0428	.0385	.0392
Magnesium	.0164*	.0040	.0012
Phosphorus	.0112	.0089	.0012
Potassium	1.4409	.8772	.1618
Sodium	.0003	.0026	.0010
Crude protein	31.7166	63.1011	8.7055
IVOMD	105.9608	124.2633	28.4418
df	2	13	48

[a]Test farm using paddock/farm as an error term.

[b]Represents degrees of freedom.

*P<0.10.

**P<0.05.

***P<0.01.

TABLE 26. SUMMARY OF ANALYSES OF VARIANCE OF SERUM AND BONE MACROMINERALS--MEAN SQUARES BY SEASON

Response	Farm[a]	Class[b]	Farm x class	Residual
		Rainy season		
Serum				
Calcium	.9006	6.3642+	1.0086	.5271
Magnesium	.0212	.2455	.2165	.0621
Phosphorus	1.1413	37.6635**	1.4961	1.7711
df[b]	2	2	3	85
		Dry season		
Calcium	4.5136	13.1692	4.7069	.5134
Magnesium	.9606*	1.1426*	.1152	.0790
Phosphorus	4.6465	58.6009**	2.0116	.9469
		Rainy season		
Bone				
Ash	5.9424	79.9057**	1.5355	3.7976
Calcium	2.1997	16.3216	3.6251	.9316
Magnesium	.0026	.0229+	.0030	.0026
Phosphorus	6.3506	42.3664+	6.3914	2.6365
		Dry season		
Ash	91.1334	268.2370	49.5250	6.4696
Calcium	34.7895+	40.1906+	2.5943	6.7941
Magnesium	.0195+	.0041	.0015	.0045
Phosphorus	12.2519	9.4667	4.0726	2.0671
df	2	2	2	70

[a]Test farm and class using farm * class as an error term.

[b]Represents degrees of freedom.

+P<0.10.

*P<0.05.

**P<0.01.

TABLE 27. SUMMARY OF ANALYSIS OF VARIANCE OF WHOLE BLOOD VARIABLES--MEAN SQUARES BY SEASON

Response	Farm[a]	Class[b]	Farm x class	Residual
		Rainy season		
Hemstocrit	315.9647+	2.5048	53.9255	9.5438
Hemoglobin	48.1726*	1.3066	4.9817	1.0322
Leucocytes	57588448?**	20004183	16111240	16108862
Neutrophils	730.4968	382.5963	186.2268	67.7747
Lymphocytes	1636.91*	480.6150	221.5605	75.1212
Monocytes	9.4986	.7951	4.3139	2.9106
Basophils	.1138	.0695	.0985	.0524
df	2	2	3	81
		Dry season		
Hemstocrit	261.9621+	57.3294	60.2374	16.6150
Hemoglobin	30.6456	8 7337	10.4269	2.5663
Leucocytes	5?276064**	1993866	4251604	2798545
Neutrophils	1729.55	1048.91	1024.33	526.56
Lymphocytes	540.2386	317.2786	1148.18	197.5488
Monocytes	.1822	1.7832	2.6948	197.5488
Basophils	2.3330	.3309	.7082	.4751
df	2	2	4	96

[a]Test farm and class using farm * class as an error term.

[b]Represents degrees of freedom.

+P<0.10.

*P<0.05.

**P<0.01.

TABLE 28. BLOOD SERUM AND BONE MACROMINERAL CORRELATION COEFFICIENTS AS RELATED TO SEASON[a]

Variable	Serum Ca	Serum Mg	Serum P	Bone Ca	Bone Mg	Bone P	Bone Ash
Rainy season							
Serum							
Calcium	1.000						
Magnesium	.263	1.000					
Phosphorus	.673*	-.137	1.000				
Copper	.493	.452	-.175				
Iron	-.176	-.173	-.086				
Selenium	-.448	.112	.020				
Zinc	-.227	-.156	-.557				
Dry season							
Calcium	1.000						
Magnesium	-.486	1.000					
Phosphorus	.765*	-.407	1.000				
Copper	-.414	-.011	-.515*				
Iron	.659*	-.753*	-.307				
Selenium	-.284	-.367	-.077				
Zinc	.778*	-.583*	.566*				
Rainy season							
Bone							
Calcium				1.000			
Magnesium				-.674*	1.000		
Phosphorus				.620*	-.465	1.000	
Ash				.796*	-.939**	.486	1.000
Dry season							
Calcium				1.000			
Magnesium				.402	1.000		
Phosphorus				.805*	.665*	1.000	
Ash				.977**	.315	.722*	1.000

[a]Correlation coefficients based on 8, 9 (rainy, dry) means for serum: and 8, 7 (rainy, dry) for bone.

*P<0.10.

**P<0.05.

**P<0.01.

TABLE 29. CORRELATION COEFFICIENTS BETWEEN BLOOD AND LIVER AND BONE MINERALS AS RELATED TO SEASON[a]

Variable	Season	Blood serum Ca	P	Mg	Zn	Fe	Cu	Se
Liver								
Mn	rainy	.290	.246	-.080	-.071	-.039	.002	.109
	dry	-.209	.169	.646	-.188	-.913**	-.433	.185
Zn	rainy	.302	.409	-.127	-.642+	-.268	-.405	.120
	dry	.186	.645	-.729*	.554	.497	-.024	.540
Fe	rainy	.356	.296	.154	-.586+	-.143	-.251	.240
	dry	.530	.737+	-.251	.907**	.000	.789+	-.042
Cu	rainy	.587	.063	.425	.259	-.476	.869**	-.536
	dry	-.274	.032	-.803*	-.059	.730+	.715+	.552
Co	rainy	-.705*	-.353	-.485	-.244	-.050	-.758*	.353
	dry	.078	.036	.805*	-.131	-.817*	-.551	-.091
Mo	rainy	.196	.115	.469	-.010	.564	.049	.127
	dry	-.869*	-.459	.156	-.537	-.412	.361	.267
Se	rainy	-	-	-	-	-	-	-
	dry	-.238	.671	-.239	-.076	-.237	.062	.842*
Bone								
Ash	rainy	-.518	-.864**	.346	.468	-.155	.314	.024
	dry	-.384	-.564	.468	-.841*	-.354	.534	.125
Ca	rainy	-.463	-.673+	.428	.329	.204	.170	.481
	dry	-.397	-.491	.377	-.785+	.353	.525	.255
P	rainy	.155	-.226	.850**	-.271	-.211	.271	.310
	dry	-.220	-.147	.130	-.610	-.211	.556	.365
Mg	rainy	.487	.845**	-.491	-.445	.169	-.351	.062
	dry	.317	.441	-.322	-.585	-.021	.106	.675+

[a]Correlation coefficients based on 8, 6 means for rainy and dry seasons in liver and 8, 7 means for rainy and dry in bone.

+P<0.10.

*P<0.05.

**P<0.01.

TABLE 30. SUMMARY OF ANALYSES OF VARIANCE OF SOIL MICROMINERALS--MEAN SQUARES BY SEASON

Response	Farm[a]	Paddock/farm	Residual
		Rainy season	
Boron	.0001	.0104	.0094
Copper	11.0098	6.1491	3.2721
Iron	362715.97[+]	113986.02	39531.26
Manganese	296.88	138.29	10.29
Zinc	6.8931*	1.5172	.2933
df	2	12	44
		Dry season	
Boron	.1016**	.0118	.0044
Copper	5.9755[+]	1.7999	.2017
Iron	837900.09*	178337.50	41748.07
Manganese	70.8478	50.7362	4.8890
Zinc	2.9718	1.9128	.3450
df	2	13	38

[a]Test farm using paddock/farm as an error term.

[b]Represents degrees of freedom.

[+]P<0.10.

*P<0.05.

**P<0.01.

TABLE 31. SUMMARY OF ANALYSES OF VARIANCE OF FORAGE MICROMINERALS--MEAN SQUARES BY SEASON

Response	Farm[a]	Paddock/farm	Residual
		Rainy season	
Cobalt	.0440**	.0047	.0021
Copper	1.0951	21.6271	5.2256
Iron	10611.83	17280.00	1972.74
Manganese	10420.08	29354.30	3709.55
Molybdenum	4.4002*	1.1388	.2380
Selenium	.0186**	.0029	.0031
Zinc	304.12	150.87	52.4691
df[b]	2	12	52
		Dry season	
Cobalt	.0021	.0045	.0081
Copper	3.8044	6.3543	2.5376
Iron	2303.26	5601.09	3521.46
Manganese	233382.23**	33671.88	7399.76
Molybdenum	.3952	.8585	.1740
Selenium	.0017	.0096	.0071
Zinc	231.4363[c]	71.2156	63.5348
df	2	13	49

[a]Test farm using paddock/farm as an error term.

[b]Represents degrees of freedom.

[c]P<0.10.

*P<0.05.

**P<0.01.

TABLE 32. SUMMARY OF ANALYSES OF VARIANCE OF BLOOD SERUM AND LIVER MICROMINERALS--MEAN SQUARES BY SEASON

Response	Farm[a]	Class[a]	Farm x class	Residual
		Rainy season		
Serum				
Copper	.7717	.0083	.1762	.0384
Iron	5.5228	1.4428	2.1731	.4120
Selenium	.0738[+]	.0088	.0070	.0033
Zinc	.2370[*]	.1586	.0301	.0352
df[b]	2	2	3	85
		Dry season		
Copper	.8804[+]	.4143	.1284	.0708
Iron	8.8831[*]	5.8814	1.4742	.5842
Selenium	.0155	.0035	.0040	.0011
Zinc	.1519	.8949	.2649	.1304
df	2	2	4	105
		Rainy season		
Liver				
Cobalt	.0333	.0337	.0240	.0218
Copper	12013.36[*]	1828.80	2220.48	2188.18
Iron	186258.84	380858.81	150557.0	
Manganese	84.7558[*]	57.6228	17.0831	5.8142
Molybdenum	.0428	.0783	.2385	.1411
Zinc	2077.01	5703.33	3206.08	410.18
df	2	2	3	42
		Dry season		
Cobalt	.0876[+]	.0118	.0007	0031
Copper	32103.09	3105.18	803.17	4147.45
Iron	152008.83	616011.81[*]	4478.48	53649.97
Manganese	120.3429	10.8981	14.8820	11.6768
Molybdenum	.0018	.0014	.0004	.0003
Selenium	.0253	.0848	.0882	.1452
Zinc	4489.88	3388.23	842.80	888.72
df	2	2	1	81

[a]Test farm and class using farm * class as an error term.

[b]Represents degrees of freedom.

[+]P<0.10.

[*]P<0.05.

[**]P<0.01.

TABLE 33. SUMMARY OF ANALYSIS OF VARIANCE OF FORAGE (PARTS) CRUDE PROTEIN, IVOMD AND MACROMINERALS--MEAN SQUARES BY SEASON

Response	Part[a]	Paddock * part/farm	Residual
		Rainy season	
Calcium	.5632**	.0212	.0700
Magnesium	.0332*	.0041	.0079
Phosphorus	.0021	.0044	.0578
Potassium	.5131	.2868	.4859
Sodium	.0000	.0002	.0005
Crude protein	828.4354**	25.1014	16.6603
IVOMD	.0000	109.7614	55.8628
df[b]	1	12	85
		Dry season	
Calcium	1.0320**	.0542	.1563
Magnesium	.0530**	.0008	.0013
Phosphorus	.0099*	.0011	.0016
Potassium	3.5430**	.2538	.2230
Sodium	.0023	.0018	.0003
Crude protein	845.0289**	12.5668	6.5530
IVOMD	1272.5860**	48.7012	22.0784
df	1	12	82

[a]Test plant part (stems, leaves) using paddock * part/farm.

[b]Represents degrees of freedom.

*p<0.10.

**P<0.05.

***p<0.01.

TABLE 34. SUMMARY OF ANALYSES OF VARIANCE OF FORAGE (PARTS) MICROMINERALS--MEAN SQUARES BY SEASON

Response	Part[a]	Paddock * part/farm	Residual
		Rainy season	
Cobalt	.0010	.0011	.0046
Copper	9.0607	17.7774	7.6907
Iron	10617.96[+]	3121.55	2535.73
Manganese	6760.05	5746.69	2742.53
Molybdenum	14.6461**	.3028	.1814
Selenium	.0059	.0055	.0034
Zinc	306.7934*	66.5135	51.6941
df[b]	1	12	65
		Dry season	
Cobalt	.0004	.0046	.0056
Copper	1.6003	1.1553	2.7159
Iron	18260.45*	2712.29	5060.09
Manganese	126730.53**	9106.26	6506.90
Molybdenum	.0073	.5432	.6608
Selenium	.0060[+]	.0016	.0023
Zinc	202.0959	74.5792	50.1032
df	1	12	62

TABLE 35. FORAGE MACROMINERAL, CRUDE PROTEIN AND IVOMD CONCENTRATIONS AS RELATED TO SEASON AND SPECIES (DRY BASIS).

Variable	Critical level	Season	B. obtegrum			O. lanatus t.			G. lanatus hanyi			S. elongata		
			Mean	S E	% Def	Mean	S E	% Def	Mean	S E	% Def	Mean	S E	%
Ca %	< 0 2[C]	rainy	0 11	0 03	0	0 11	0 01	6	0 21	0 03	33			
		dry	0 20	0 02	11	0 28	0 01	26	0 10	0 02	1			
K %	< 0 5[B]	rainy	1 70	0 15	0	1 15	0 16	0	1 08	0 14	0			
		dry	1 85	0 08	5	1 00	0 11	1	1 60	0 11	8			
Mg %	< 0 11[C]	rainy	0 11	0 03	81	0 10	0 01	11	0 11	0 00	88			
		dry	0 08	0 00	83	0 10	0 01	78	0 08	0 00	100			
Na %	< 0 05[C]	rainy	0 01	0 00	100	0 03	0 00	94	0 04	0 00	94			
		dry	0 01	0 00	97	0 04	0 01	95	0 04	0 01	88			
P %	< 0 16[C]	rainy	0 21	0 01	0	0 26	0 01	0	0 28	0 01	0			
		dry	0 11	0 00	77	0 10	0 02	51	0 11	0 01	50			
CP %	< 1[B]	rainy	18 8	1 20	0	11 0	0 85	6	28 1	0 85	1			
		dry	8 0	0 48	11	11 0	0 80	11	10 7	0 21	0			
IVOMD %		rainy	61 1	1 01		70 1	1 11		71 0	0 15				
		dry	51 0	1 02		61 7	1 28		56 7	1 41				

TABLE 35.--CONTINUED.

Variable	Critical level	Season	P. clandestinum			T. repens			P. arundinacea			Weed		
			Mean[a]	S.E.[b]	% Diff	Mean	S.E.	% Diff	Mean	S.E.	% Diff	Mean	S.E.	% Diff
Ca %	< 0.2[c]	rainy	0.11	a 03	18	1.46	0.11	0	0.67	0.02	0	0.17		
		dry	0.37	0.05	0	1.87		-				0.1		
K %	< 0.5[c]	rainy	2.81	0.28	a	3.73	0.28	a	4.03	4.56	a	2.75		
		dry	1.68	0.10	0	2.22	-					1.80		
Mg %	< 0.12[c]	rainy	0.22	0.02	10	0.26	0.04	0	0.21	0.0		0.16		
		dry	0.22	0.01	0	0.26			-					
Mn, %	< 0.04[c]	rainy	0.01	0.00	100	0.11	0.02	25	0.08	0.00				
		dry	0.02	0.00	100	0.08	-		2					
P %	< 0.10[c]	rainy	0.06	0.02	10	0.12	0.02	0	0.01	0				
		dry	0.17	0.03	66	0.22								
CP %	< 7[d]	rainy	15.5	1.09	0	20.6	1.12	0	17.0					
		dry	9.0	0.54	0	21.0			-					
IVOMD %		rainy	51.5	2.11		70.1	2		70.5	1				
		dry	52	1.72		70.7			-					

[a] Means based on the following number of samples: 12, 36 (rainy dry) for A. odoratum; 30, 18 (rainy dry) for H. lanatus L.; 18 (rainy dry) for H. lanatus hays; 10, 5 (rainy dry) for P. clandestinum; 8, 4 (rainy, dry) for T. repens; 2, 0 (rainy dry) for P. arundinacea; 4, 1 (rainy, dry) for O. glumaza".

[b] Standard error of means.

[c] NRC (1980).

[d] Minson and Milford (1967).

TABLE 36. FORAGE MICROMINERAL CONCENTRATIONS AS RELATED TO SEASON AND SPECIES (DRY BASIS).

Variable	Critical level	Season	A. plicatum			P. lanatum, native			P. lanatum, hayn			P. glume a		
			Mean[a]	S.E.[b]	% Def	Mean	S.E.	% Def	Mean	S.E.	% Def	Mean	S.E.	% Def
Cu, ppm	< 3[d]	rainy	8.63	0.53	84	7.02	0.88	69	7.20	0.88	63	7.25		
		dry	2.03	0.27	93	2.36	0.28	100	3.84	0.83	89			
Co, ppm	< 0.1[e]	rainy	0.05	0.00	52	0.04	0.01	69	0.03	0.00	74			
		dry	0.04	0.00	100	0.00	0.00	85	0.03	0.00	100			
Fe, ppm	<30[e]	rainy	196	18.1	0	0.03	7.61	0	98	15.8				
		dry	140	10.3	0	118	15.3	0	157	27.5				
Mn, ppm	<20[e]	rainy	291	30.5	0	210	18.1	0	325	15.				
		dry	368	20.0	0	387	23.0	0	388	23.6				
Mo, ppm	> 0[d]	rainy	1.32	0.14		0.03	0.18		1.18	0.				
		dry	0.66	0.11		0.38	0.03		0.95					
Se, ppm	< 0.1[e]	rainy	0.10	0.01	82	0.12	0.01	26						
		dry	0.03	0.00	33	0.09	0.0							
Zn, ppm	<20[e]	rainy	23.3	1.18	15	18.7								
		dry	22.0	1.13	0	15.8								

TABLE 36.--CONTINUED.

Variable	Critical level	Season	P glandertinum			T repens			P arundinacea			Overall	
			Mean[a]	± E	% Def	Mean	± E	% Def	Mean	± E	% Def	Mean	± D
Mn, ppm	< 2[c]	rainy	8 91	1 09	20	10 1	1 11	0	0 27	1 22	0	2 78	32
		dry	5 22	0 79	09	9 0	-	-	-	-	-	1 01	94
Cu, ppm	< 0 1[c]	rainy	0 16	0 02	20	0 12	0 05	56	0 06	0 02	100	0 01	28
		dry	0 12	0 03	09	0 02	-	-	-	-	-	0 0	
Fe, ppm	<30[c]	rainy	52	10 0	30	94	12 3	0	52	23 0			
		dry	01	12 0	0	122	-			-			
Mn, ppm	<10[c]	rainy	120	10 0	10	109	0 51	0	85	2 09			
		dry	261	25 0	0	110							
Mo, ppm	> 0[d]	rainy	0 27	0 10	-	1 01	0 01		0 01	0 01			
		dry	0 10	0 01	-	0 29	-			-			
Se, ppm	< 0 1[c]	rainy	0 14	0 02	20	0 10	0 05	25	0 08	0 03			
		dry	0 20	0 09	60	0 04		-					
Zn, ppm	<20[c]	rainy	33 0	8 01	10	30 5	3 51	0	12 1	0 0			
		dry	22 0	9 60	09	18.5							

[a]Means based on the following number of samples: 12, 30 (rainy, dry) for P. glandertinum; 10, 10 (rainy, dry) for T. repens; 1, 1 (rainy, dry) for P. arundinacea; 8, 2 (rainy, dry) for O. glomerata.

[b]Standard error of means.

[c]NRC (1980).

[d]Underwood et al. (1984).

TABLE 37. OVERALL FORAGE MINERAL CONCENTRATION IN DIFFERENT SPECIES (DRY BASIS)

Variable	Critical level	A. aberratum Mean[a]	1 Ref	O. lanatus Mean	1 Ref	O. lanatus hanys Mean	1 Ref	P. glandulifera Mean	% Ref.	T. repens Mean	1 Ref.	O. glomerata Mean	1 Ref	Mean
Ca 1	< 0.1[b]	0.29	10	0.29	17	0.11	27	0.34	1	1.11	0	0.11	33	
K 1	< 0.5[b]	1.25	1	1.11	0	1.61	0	2.41	1	1.41	0	1.86		
Mg 1	< 0.12[b]	0.09	77	1.11	10	0.11	11	0.21	1	0.11	0	1.11		
Na 1	< 0.05[b]	0.01	94	0.01	94	0.04	91	1.12	100	0.11	10	0.06		
P, %	< 0.16[c]	0.11	56	0.11	29	1.21	11	1.13	17	1.11	0	0.11		
Mn ppm	< 7[b]	1.11	11	0.49	86	6.11	11	1.11	10	9.06	10	7.15		
Mo, ppm	< 0.1[b]	0.01	11	0.04	01	0.01	96	0.11	11	0.10	60			
Fe ppm	<30[b]	101	0	101	0	116	0	66	11	101	0	a		
Mn ppm	<20[b]	341	0	211	0	268	0	141	1	132	0	119		
Mo ppm	> 1[c]	0.06	-	0.64	-	1.08	-	0.23	-	1.30		1.10	-	
Se ppm	< 1.1[b]	0.01	71	0.10	51	0.11	11	0.10	31	0.11	86	0.09	58	
Zn ppm	<20[b]	11.9	36	19.1	10	22.0	86	29.0	27	11.1	28	13.1	58	
Cu 1	< 1[b]	11.0	12	11.6	0	10.5	0	11.4	0	11.9	0	11.0	17	
IVOMD 1		55.1		61.1		40.7		11.5	-	69.1		11.7		

[a] Means based on the following number of samples: 11 for A. aberratum, 15 for I. lanatus L., 24 for H. [illegible] P. glandestinum; 3 for T. repens; 0 for D. glomerata; 2 for P. arundinacea)

[b] NRC (1861)

[c] Minson and Hilford (1961)

TABLE 38. SOIL ORGANIC MATTER, pH, MACROMINERAL AND MICROMINERAL CORRELATION COEFFICIENTS AS RELATED TO SEASON.[a]

Variable	OM	pH	Al	Ca	P	Mg	S	Mn	Cu	Fe	Mn
						Rainy season					
Organic matter	1 000										
pH	341	1 000									
Aluminum	.354	034**	1 000								
Calcium	000**	703**	704**	1 000							
Phosphorus	156	— 526	118	— 185	1 000						
Magnesium	841**	196*	— 571*	000**	— 311	1 000					
Potassium	302	111	025	139	111	119	1 000				
Sodium	000**	000*	— 668*	138**	— 129	961**	029	1 000			
Copper	346	— 114	000†	046	000	161	358	185	1 000		
Iron	000	— 309	111*	146	561*	014	425	011	419	1 000	
Manganese	— 111**	686*	— 602*	— 701**	129	861**	268	791**	111	010	
Zinc	— 888**	208	— 126	541*	111	818*	— 858**	561*	411	102†	
Boron	— 263	119	— 348	111	111	111	111	121	146	211	
						Dry season					
Organic matter	1 000										
pH	— 121**	1 000									
Aluminum	239	081**	1 000								
Calcium	769**	799**	— 451*	1 000							
Phosphorus	111*	341	101	000	1 000						
Magnesium	— 704**	112**	— 111	879**	— 415*	1 000					
Potassium	— 111**	159**	108	882**	— 128	871**	1 000				
Sodium	— 881**	188**	171	888**	— 341	943**	931**	1 000			
Copper	— 761**	— 851**	121	111**	063*	888**	881**	825**	1 000		
Iron	— 181	— 117	811*	441	169	000	018	000	078	1 000	
Manganese	— 878**	116*	105	888**	000	938**	810**	884**	187**	188	
Zinc	872**	519*	081	888*	— 421*	888**	584*	774**	885**	481	
Boron	227	158	— 301	311	— 117	211	219	381	111	29	

[a] Correlation coefficients based on 19 and 11 means for rainy and dry seasons respectively

*P≤ 10

*P≤ 01

**P≤ 01

TABLE 39. FORAGE MACROMINERAL, MICROMINERAL, AND CRUDE PROTEIN CORRELATION COEFFICIENTS AS RELATED TO SEASON.[a]

Variable	Ca	P	Mg	K	Na	Cu	Fe	Mn	Zn			
					Rainy season							
Calcium	1 000											
Phosphorus	451[b]	1 000										
Magnesium	676**	251	1 000									
Potassium	190	799**	130	1 000								
Sodium	000	181	000	011	1 000							
Copper	240	111	110[b]	583*	111	1 000						
Iron	- 085	000	- 111[b]	- 115	- 110	657**	1 000					
Manganese	- 485[b]	- 111	- 511*	- 111	118	561*	411[b]	1 000				
Zinc	717*	981**	876**	541*	281	411[b]	- 206	- 183	1 000			
Cobalt	111	032	691**	951	141	180	- 111	111	461[b]	1 000		
Molybdenum	- 136	178	- 111*	181	- 341	- 111	541**	251	000	541*		
Selenium	111	376	191	429	199	019	121	- 141	281	- 111		
Protein	024	501*	811	786**	011	285	- 000	- 294	139	- 18		
					Dry season							
Calcium	1 000											
Phosphorus	640**	1 000										
Magnesium	870**	811[b]	1 000									
Potassium	956*	911**	911	1 000								
Sodium	111[b]	000	039	321	1 000							
Copper	186	548*	211	742**	281	1 000						
Iron	238	181	111	048	000	981	1 000					
Manganese	110	- 478	111	- 430[b]	000	981	291	1 000				
Zinc	869	111	235	299	355	470[b]	176	451[b]	1 000			
Cobalt	811*	108	582*	114	- 181	181	118	- 178	206	1 000		
Molybdenum	178	198	- 175	158	503*	383	117**	309	111	- 158	1 000	
Selenium	139	000	081	000	188	819	- 331	981	- 161	178	- 188	1 000
Protein	175	718**	391	831**	111	138**	181	156	565*	- 111	381	000

[a]Correlation coefficients based on 11 and 18 means for rainy and dry seasons, respectively

[b]P=0.10

*P=0.05

**P=0.01

APPENDIX C

RAW DATA

SOIL DATA CODES

OBS		= Observation number
SEASON	1	= Rainy (1987)
	2	= Dry (1988)
FARM	1	= San Jorge
	2	= Don Benito
	3	= San Francisco
PADDOCK	1	= Nevado
	2	= Papayo
	3	= Regadera
	4	= Esperanza
	5	= Tablon Alto
	6	= Pantano
	7	= Laural
	8	= Mirador
	9	= Sibaria
	10	= Pantano Amarillo
	11	= El laurel
	12	= Aguasal
	13	= Porvenir
	14	= Panama
	15	= Llanos
	16	= La Sierra
	17	= Palocaido
	18	= La Mina
	19	= Cajon
	20	= Puertas
	21	= Buenavista
	22	= Lomaciro
	23	= El Pantano
PH		= Soil pH
OM		= Soil organic matter, % dry matter
AL		= Soil aluminum, ppm dry matter
CA		= Soil calcium, ppm dry matter
P		= Soil phosphorus, ppm dry matter
MG		= Soil magnesium, ppm dry matter
K		= Soil potassium, ppm dry matter

NA	= Soil sodium, ppm dry matter
FE	= Soil iron, ppm dry matter
CU	= Soil copper, ppm dry matter
MN	= Soil manganese, ppm dry matter
ZN	= Soil zinc, ppm dry matter
B	= Soil boron, ppm dry matter

| | | |

51		7	6	4 8	20 0	406	67	12	2.0	58 8		3	789 8		0.8	4 5	7.0	9	9
57	1	7	16	5 0	26 9	778	82	7	14 4	50 7		3.0	944 0		0.8	4 2	1 6	9	
53	4	2	13	4 0	26 9	706	68	6	8 4	35 .		2.0	654.0		0.3	7 1	1 2	7	4b
54	1	7	9	4 0	25 8	365	76	7	7.7	7 7		2.3	346 0		0.5	7.7	1	6	2
55	1	3	9		-	706	52	4	10 6	39 0		2.0	715 0		0.6	2.9	1 1	6	4b
56		7	70	5 4	3.0	761	378	28	76.4	35.3		6.7	2 - 0		1 5	5.6	1 4	6	1 8
57		7	70	3 7	19 0	242	495	34	59 9	141 4		7.3	367.0		1.0	8 5	1 6	6	5
58			0	5 4	2 1	261	556	33	24 8	37.5		2.3	459.0		7 1	5 5	1 4	6	4 3
59	1	7	0	5 1	24 0	761	574	29	4 9	110 1		7 0	491-0		. 0	9 0	1 2	6	2
60			1	-	6 0	30	258	14	20 4	174 9		0 2	365 8		0 7	5 7	1 2	6	3
61	2		1	5 5	15 0	08	98	07	3 7	46 8		7 0	765.1		0 5	2 5	1 0	6	5
67	7	1	1	5 2	24 8	100	464	57	15 6	67 4		4 3	8 0		5 .	2 8	1 4	6	4
53	2	1	1	5 8	26 0	98	438	28	15 8	59 5		1.5	395 6		0.7	4 6	1 1	6	4 1
64	2	1	6	5 1	23 5	25	194	8	14.6	71 7		4.8	600 8		1 7	3 8	1 0	6	3 6
65	7	1	6	5 5	23 5		178	7	13 7	54 6		7.3	100.0		0 8	3 4	1.0	6	4 1
66	7	1	7	5.1	23 9	30	764	23	8 4	62 6		7.3	130 6		0 6	7 8	0 6	6	3 6
67	7	1	8	5 3	17 9	77	640	18	15 2	30 0		2.0	171 8		1 3	4.2	1 7	6	4 1
68	7	1	4	5.7	7 6		1514	71	74.3	167.7		16 1	479 8		3 3	5 8	4 6	6	4 1
69	7	1	4	5 7	7.6		1490	5	414 0	178.7		20.7	258 6		2 0	9 4	1 7	6	3 6
70	7	1	4	6 0	5.6		1148	13	94 4	132.6		39 1	480 8		7 9	17 2	7 3	6	3 6
71	2	1	4	5 5	5.6		1320	11	239 6	78 7		25 3	490 8		9 4	17 0	3 0	6	4 6
77	1		3	5 9	7.2		1814	79	198 0	782 9		29 9	450 0		2 0	15.2	3 1	9	3 6
73	7	1	3	5 8	7 0		618	32	169 0	187.7		18 4	480 0		2 7	10 7	2 2	6	4 1
74	7		3	5 6	4 5		1418	15	188.0	163 8		10 0	500 0		7 2	5 6	7 0	6	4 1
75	7	1	0	5 0	3 1	54	1740	6	262.6	122 6		64 4	286 0		4 3	71 4	3 4	6	2 2
76	7	1	7	5 5	4 3		1118	5	152.0	101 4		23 0	240 0		1 3	17 7	1 9	6	1 0
77	2	1	2	5 8	4 0		1408	5	252.2	97 8		18 4	550 0		2 7	15 2	3 8	6	2 2
78	2	1	2	5 8	9 6		926	5	712.4	124 8		13 0	560 0		2 7	17 7	3 3	6	2 2
79	7	1	7	5 8	4 0		1118	5	54 6	113.1		18 4	580 0		7 6	18 4	3 9	6	2 7
80	7	2	13	5 3	22 7	126	1637	44	25 2	58 3		7 0	360 0		0 2	6 5	1 2	6	3 6
81	7	2	10	4.8	24 6	315	376	31	14 9	46 0		7 3	252 0		0 1	3 6	0 7	6	2 7
87	7	2	13	4 7	1 4	329	730	66	- -	7		4 6	405 0		0 1	0 8	0 7	6	4 1
83	7	2	13	4 8	22.0	477	620	57	18 0	31.2		2 9	575 0		0 1	6 3	7 0	6	3 7
84	2	2	14	4 4	18 7	1090	58	14	16 8	58.5		7 3	300 0		0 7	0 0	1 3	6	4 1
85	7	2	14	4.3	19 2	810	78	7	18 1	42 9		7.0	1050 0		0 1	3 0	1 2	6	4 1
86	7	2	14	4.5	9 7	738	74	14	16 8	46 1		3 7	1730 0		0 0	9 4	2 1	6	2 7
87	7	3	10	4 4	20 8	811	72	45	8 4	19 3		2 3	550 0		1 1	3 6	7 8	6	3 2
88	2	2	10	4.8	22 0	360	48	74	6.8	15 6		7 3	320.0		0 7	0 0	2 4	6	7 7
89	7	7	11	5 0	15.8	376	22	20	5 8	11 7		7 3	430 0		0 2	0 5	1 8	6	3 2
90	2	7	15	5 7	18.7	306	30	25	6 8	11 7		7 3	560.0		0 4	4 2	7 7	6	2 7
91	2	7	15	4 8	16 3	144	8	78	7 7	19.5		7 3	710.0		0 5	3.1	7 7	6	7 2
97	7	7	15	4.8	17.2	162	76	36	9 8	23.4		7 0	170 0		0 2	3 2	2 8	6	1 3
93	2	7	15	5.0	17 7	100	14	19	6 8	31 7		7 0	320 0		0 4	3 5	7 3	6	7 7
94	2	3	10	5 1	29 3	960	110	10	20 4	58.7		7 3	90.0		1 6	3 0	1 3	6	4 2
95	2	0	19	4 9	71.4	315	64	18	17 0	72 0		7 3	159 0		1 6	3 4	1 0	6	0 0
96	2	3	19	4 0	10 7	450	156	19	16 8	58 5		7 3	170 0		1 8	4 5	1 1	6	1 8
97	7	3	10	5.2	10 7	360	124	15	70 4	10 5		3	172 0		1 6	4 0	1 1	6	1 3
98	7	3	17	5 0	9 1	351	816	17	28 8	47 0		3 3	760 0		1 6	5 5	1 1	6	7 7
99	7	3	17	4 8	20 3	531	790	38	10 0	81 9		2 0	740 0		1 7	3 7	1 1	6	2 2
100	7	0	17	4 8	27 5	531	232	28	23 4	28 7		7 3	270 0		1 0	4 0	1 7	6	1 7

001	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
01	[illegible]	[illegible]	7	[illegible]	[illegible]	[illegible]	604	44	.5 [illegible]	9.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
102	[illegible]	3	21	5 [illegible]	[illegible]	47	326	36	[illegible]	105.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
03	[illegible]	3	21	5 [illegible]	[illegible]	[illegible]	600	50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
104	[illegible]	[illegible]	[illegible]	5 [illegible]	[illegible]	270	464	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
05	2	[illegible]	21	5 [illegible]	[illegible]	297	456	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
06	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	702	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
07	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	550	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
108	2	[illegible]	[illegible]	[illegible]	[illegible]	621	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
109	2	3	22	[illegible]	[illegible]	351	76	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
110	[illegible]	3	23	[illegible]	[illegible]	[illegible]	330	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
111	[illegible]	3	[illegible]	[illegible]	[illegible]	435	330	30	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
112	[illegible]	3	[illegible]	[illegible]	[illegible]	450	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	2	3	23	[illegible]	[illegible]	693	162	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FORAGE DATA CODES

OBS		= Observation number
SEASON	1	= Rainy (1987)
	2	= Dry (1988)
FARM	1	= San Jorge
	2	= Don Benito
	3	= San Francisco
PADDOCK	1	= Nevado
	2	= Papayo
	3	= Regadera
	4	= Esperanza
	5	= Tablon Alto
	6	= Pantano
	7	= Laural
	8	= Mirador
	9	= Sibaria
	10	= Pantano Amariilo
	11	= El laural
	12	= Agua Sal
	13	= Porvenir
	14	= Panama
	15	= Llanos
	16	= La Sierra
	17	= Faiocaido
	18	= La Mina
	19	= Cajon
	20	= Puertaa
	21	= Buenaviata
	22	= Lomaciro
	23	= Pantano
SPECIES	1	= Anthoxanthum odoratum
	2	= Hoicus lanatus L (native)
	3	= Panniastum ciandastinum
	4	= Trifoiium repana
	5	= Featuca arundinacea
	6	= Dactyiis glomerata
	7	= Nolcus lanatus basyn (imported)
PART	1	= Stam
	2	= Leaf
	3	= Whole plant

CA	= Forage calcium, % dry matter
P	= Forage phosphorus, % dry matter
MG	= Forage magnesium, % dry matter
K	= Forage potassium, % dry matter
NA	= Forage sodium, % dry matter
CU	= Forage copper, ppm dry matter
FE	= Forage iron, ppm dry matter
MN	= Forage manganese, ppm dry matter
ZN	= Forage zinc, ppm dry matter
CO	= Forage cobalt, ppm dry matter
MO	= Forage molybdenum, ppm dry matter
SE	= Forage selenium, ppm dry matter
CP	= Forage crude protein, % dry matter
IVOMD	= Forage in vitro organic matter digestibility, % dry matter

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															SE			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

BLOOD SERUM DATA CODES

OBS		= Observation number
SEASON	1	= Rainy (1987)
	2	= Dry (1988)
FARM	1	= San Jorge
	2	= Don Benito
	3	= San Francisco
CLASS	1	= Pregnant-lacteting ewe
	2	= Lamb
	3	= Yearling
NUMBER		= Animal number
CA		= Serum calcium, mg/dl
MG		= Serum magnesium, mg/dl
P		= Serum phosphorus, mg/dl
ZN		= Serum zinc, ppm
FE		= Serum iron, ppm
CU		= Serum copper, ppm
SE		= Serum selenium, ppm

S	TRAS	A	M	CLASS	NUMBER	DA						SG
	1	1	1	620	0 0			1 01		1		0.342
2			1	1420	7 5			0 65				0 187
3	1	1	1	2478	9 3			0 60	2 05			0 155
4	1		2	3450				0 65	2 17			0 240
5			1	2946	1	4		0 4	1 49	05		0 97
6				3632	0 5			0 78	1 66			0 135
7			1	4??	3			0 43	2 30			0 090
8			1	4810	10 0			0 92	2 47	0 94		0 116
9			1	4342	10 1			0 97	2 33	0 91		0 11
			3	5429	10			0 88	1 29			0 174
		1	4	5632			4 00	1	1 32	0 57		0 61
10	4			5840	9 4		4 71	0 4	1 88	0 22		0 129
11			3	5883	11 3	2 27	7 43	0 5	3 21	0 50		0 090
				5916	0 0		5 14	0 74	1 11	0 17		0 126
12		1	3	6233	6 6		3 00	0 44	1 20	0 31		0 065
13			2	6236	10 6	17	5 71	0 46	2 05	0 93		0 052
14			3	6413	10 3	1 54	8 86	0 36	1 90	0 68		0 135
15			3	6477	9 9	2 24	7 86	0 53	2 1?	0 61		0 077
16				6806	10 4	2 35	5 36	0 80	2 07	0 72		0 084
17		1	3	6913	10 6	2 27	5 57	0 72	3 06	0 71		0 090
18			2	6931	0 3	2 2	4 00	0 78	2 23	0 50		0 058
19			2	6967	10 1	1 63	5 14	0 69	1 81	0 77		0 077
20	1		2	6981	6 7	2 16	4 14	0 66	1 21	0 70		0 060
21	1	1		6993	10 2	2 35	5 00	0 66	2 40	0 70		0 090
22			2	7272	10 5	2 2	5 57	0 70	3 50	0 36		0 052
23	1	1	2	7243	10 1	2 16	5 71	1 10	2 55	0 89		0 060
24	1	1	2	7520	10 1	2 20	4 57	0 74	3 28	0 66		0 129
25	1	1	1	7659	8 6	1 96	3 43	0	2 27	0 00		0 213
26	1	1	2	7a145	0 6	2 41	4 29	0 83	3 24	0 66		0 043
27	1	1	2	76254	10 7	2 29	6 86	0 81	3 30	1 03		0 232
28	1	1	2	76111	10 3	2 27	4 71	0 58	3 09	0 85		0 090
29	1	1	2	761 9	10 6	2 09	5 86	0 90	3 36	0 65		0 071
30	1	1	1	76131	5 3	2 01	3 57	0 57	3 25	0 46		0 065
31	1	1	2	76134	9 2	2 19	5 66	0 64	3 52	0 84		0 077
35	1	1	2	76142	0 6	1 16	5 29	0 50	3 19	0 70		0 103
36	1	1	2	76166	10 5	2 22	4 43	0 91	3 21	0 84		0 140
				2	10 3	2 20	6 71	0 69	2 35	0 54		0 014
38	1	2	1	22	5 5	2 43	3 86	0 75	2 50	0 76		0 171
39	1	2	3	46	10 1	2 16	5 71	0 57	3 15	0 88		0 279
40	1	2		68	10 2	1 65	3 86	0 83	2 58	0 76		0 209
41	1	2	2	76	6 2	1 24	4 14	0 60	2 76	0 91		0 243
42	1	2	2	77	6 0	1 37	5 71	0 56	3 35	0 40		0 029
46	1	2	1	78	10 6	2 11	8 00	0 72	3 17	0 37		0 157
44	1	2	2	78	8 0	0 64	2 29	0 74	3 33	0 38		0 093
45	1	2	1	88	7 5	2 02	3 14	0 47	1 49	0 38		0 114
46	1	2	1	102	9 6	1 82	3 86	1 24	2 93	0 47		0 207
47	1	2	1	106	8 2	2 35	6 14	0 72	1 47	0 52		0 214
48	1	2	3	107	10 3	2 31	6 23	0 39	2 20	0 80		0 179
49	1	2	1	110	8 0	1 50	6 71	0 82	2 44	0 72		0 143
50	1	2	3	111	10 2	2 21	4 85	0 62	1 49	0 76		0 350

		FARM	C			MS	P	K	FE	^U	SE

LBS	BA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
101	2	[illegible]	[illegible]	[illegible]	[illegible]	5	2.23	[illegible]	8.67	0.[illegible]	1.56	0.006
0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6	[illegible]	3.87	[illegible]	1.47	0.[illegible]	0.049
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.68	0.[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]

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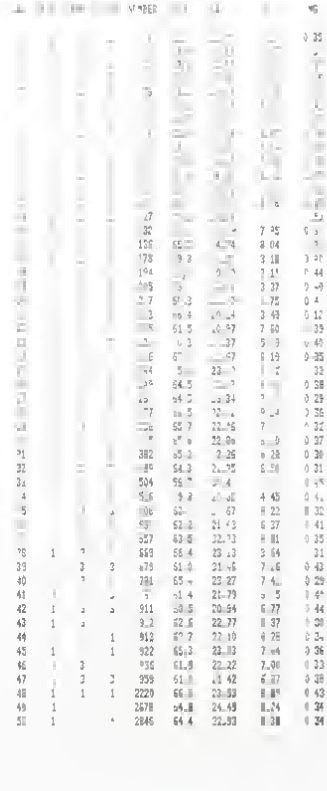
BONE DATA CODES

OBS		= Observation number
SEASON	1	= Rainy (1987)
	2	= Dry (1988)
FARM	1	= San Jorge
	2	= Don Benito
	3	= San Francisco
CLASS	1	= Pregnant-lactating ewe
	2	= Lamb
	3	= Yearling
NUMBER		= Animal number
ASH		= Bone ash, % dry, fat-free basis
CA		= Bone calcium, % dry, fat-free basis
P		= Bone phosphorus, % dry, fat-free basis
MG		= Bone magnesium, % dry, fat-free basis



OBS	[illegible]	[illegible]	CLASS	NUMBER	ASH	CA	P	MG
[illegible]				[illegible]	66.3	24.13	5.55	0.38
[illegible]	1	1		4208	[illegible]	[illegible]	3.75	0.34
[illegible]	1			4810	64.0	20.01	8.58	0.30
[illegible]	1			494	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]				[illegible]	56.[illegible]	[illegible]	[illegible]	0.[illegible]3
[illegible]	1			[illegible]	[illegible]	22.30	[illegible]	[illegible]
[illegible]				5840	63.4	[illegible]	[illegible]	[illegible]
[illegible]				59[illegible]	[illegible]	[illegible]31	[illegible]	[illegible]
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.40
61				[illegible]	55.[illegible]	[illegible]1.15	6.56	[illegible]
62				[illegible]	[illegible]	17.29	[illegible]	[illegible]
63			[illegible]	[illegible]	[illegible]1.1	2[illegible].42	7.7[illegible]	0.31
64			[illegible]	69[illegible]7	59.1	21.51	7.[illegible]	0.40
[illegible]			3	[illegible]	[illegible]	[illegible]32	[illegible]	0.39
[illegible]			[illegible]	7243	62.5	22.54	8.07	0.38
[illegible]		1	[illegible]	7272	58.[illegible]	22.18	5.46	0.33
[illegible]				7520	61.6	22.08	5.05	0.33
69				7558	[illegible]	[illegible]3.74	8.54	0.30
[illegible]			[illegible]	[illegible]140	63.7	22.22	8.94	0.44
[illegible]			3	[illegible]	56.4	2[illegible].07	5.94	0.38
[illegible]				[illegible]	57.7	20.34	3.69	0.36
73	[illegible]		2	[illegible]	[illegible]	21.71	7.13	0.41
74			3	70	[illegible]	20.81	8.26	0.30
75	[illegible]		3	35	[illegible]	23.40	[illegible].67	0.43
76	[illegible]		3	115	54.[illegible]	2[illegible].33	8.67	0.[illegible]2
[illegible]			[illegible]	[illegible]	75.8	[illegible]0.59	15.47	0.86
[illegible]	[illegible]	[illegible]	1	137	[illegible]4.5	[illegible]	7.[illegible]	0.41
[illegible]	[illegible]		3	38	64.6	23.20	5.48	0.35
80	[illegible]		[illegible]	47	[illegible]4.9	[illegible]	[illegible]	0.37
[illegible]			3	51	64.5	22.17	8.24	0.42
[illegible]		[illegible]		[illegible]	[illegible]	[illegible]3.05	[illegible]	[illegible]39
83	[illegible]	[illegible]	3	225	65.1	22.61	7.[illegible]2	0.44
[illegible]4	[illegible]	[illegible]	3	225	65.[illegible]	15.54	8.40	0.32
85	[illegible]	3	1	233	64.4	22.1[illegible]	7.22	0.29
86	2	3	1	234	65.5	22.36	[illegible]	0.26
87	2	3	1	236	62.1	20.02	6.25	0.[illegible]3
88	2	3	1	242	[illegible]	21.[illegible]	5.39	0.37
89	2	3	3	318	60.4	20.05	5.33	0.41
90	2	3	3	331	[illegible]	10.46	4.98	0.43
91	2	3	3	356	59.9	20.93	7.04	0.39
92	[illegible]	3	3	[illegible]57	60.6	20.45	8.68	0.43
93	2	3	3	358	61.7	10.16	6.05	0.42
94	2	3	3	3[illegible]2	60.7	21.37	8.52	0.42
95	2	3	1	421	64.8	22.46	8.31	0.43
96	2	3	1	457	63.2	21.65	7.97	0.37
97	2	2	3	473	65.8	23.20	8.30	0.43
98	2	3	3	604	59.9	22.50	4.32	0.46
99	2	[illegible]	3	808	81.5	21.13	3.47	0.36
100	2	3	3	810	81.8	21.13	8.[illegible]3	0.43

[illegible]	YEAR	[illegible]	[illegible]ASE	[illegible]BER	ASH	LA	[illegible]	[illegible]
1	2		1	[illegible]5	57.7	[illegible]10	[illegible]	[illegible]
[illegible]			3	[illegible]3	[illegible]	[illegible]5	[illegible]	[illegible]
[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		[illegible]	3	[illegible]	[illegible]4	[illegible]	[illegible]	[illegible]
[illegible]			1	[illegible]5	57.[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			2	[illegible]1[illegible]	6[illegible]	[illegible]	[illegible]	[illegible]
[illegible]			[illegible]	[illegible]5	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]		2		[illegible]	[illegible]	2[illegible]	[illegible]	[illegible]
[illegible]		3		[illegible]		[illegible]0	[illegible]	[illegible]4
[illegible]			1	[illegible]8	[illegible]9.8	[illegible]	[illegible]	[illegible]44
[illegible]			3	[illegible]55	52.[illegible]	[illegible]1[illegible]	3.[illegible]	0.[illegible]
[illegible]				[illegible]9	50.[illegible]	[illegible]4	[illegible]5	0.41
[illegible]	1	3	1	[illegible]	[illegible]	[illegible].09	3.44	0.39
[illegible]				[illegible]7	[illegible]	[illegible].57	6.38	0.43
[illegible]			1	[illegible]3	[illegible]1	[illegible].5[illegible]	3.11	0.42
[illegible]	[illegible]	3	3	[illegible]09	59.[illegible]	10.43	[illegible]0	0.43
[illegible]			1	[illegible]386	[illegible]6.3	[illegible]3.07	3.35	0.36
[illegible]			3	10[illegible]	52.6	32.36	7.72	0.44
[illegible]			1	[illegible]915	60.6	2[illegible].34	7.03	[illegible].34
[illegible]		1	1	[illegible]40	68.7	24.26	7.05	0.33
[illegible]	1		1	3916	67.3	23.04	7.06	0.35
122	1		1	5806	66.4	22.54	[illegible]	0.31
23	1		1	5910	66.0	[illegible]	[illegible]	[illegible]36
34	2		1	5960	65.3	31.60	6.64	0.27
25	2		1	59[illegible]8	[illegible]8.3	21.93	7.3[illegible]	0.27
[illegible]			[illegible]	7[illegible]99	[illegible]	23.14	[illegible]	0.25
[illegible]7	1		3	7417	[illegible]8.3	20.72	4.30	0.33
[illegible]8			3	7[illegible]3	[illegible]4.0	20.94	[illegible]75	0.37
[illegible]	[illegible]	1	3	[illegible]357	[illegible]5.1	23.0[illegible]	5.[illegible]	0.36
[illegible]0	[illegible]		3	7891	[illegible]3.9	2[illegible]	[illegible]0	0.32
[illegible]			1	7362	53.9	[illegible]30	5.53	0.34
[illegible]			2	7967	49.0	16.45	5.14	0.29
33	[illegible]	[illegible]	2	[illegible]371	52.9	[illegible]	4.38	0.31
134			2	[illegible]377	52.6	10.25	5.31	0.31
135	2		[illegible]	7331	41.6	14.20	4.94	0.37
36	2	[illegible]	[illegible]	7983	48.9	17.28	[illegible]57	0.32
[illegible]7	2	1	3	7384	48.4	16.30	4.41	0.33
[illegible]		1	1	7553	51.[illegible]	15.[illegible]7	[illegible].63	[illegible].35
[illegible]9	[illegible]	1	[illegible]	422[illegible]4	67.[illegible]	23.19	7.85	[illegible].34
140			1	58170	66.3	23.62	7.17	0.35
141	3		1	69142	65.8	34.19	8.65	0.33
143	2	1	3	76131	63.9	33.69	—	0.31
142	2	1	3	76301	[illegible]6.0	33.47		0.41
44	2		3	78143	65.[illegible]	18.63	4.70	0.34
145	2	[illegible]	3	78163	65.5	22.69	—	0.33
46	2	1	3	78203	64.4	31.20	5.07	0.31
147	2	1	3	78[illegible]05	40.4	14.44	4.10	0.28
148	3	1	3	78364	48.4	16.[illegible]6	3.89	0.31
149	3		3	78278	41.4	13.72	4.56	0.29
150	3	1	2	79100	46.8	15.34	3.95	0.30

WHOLE BLOOD DATA CODES

OBS		= Observation number
SEASON	1	= Rainy (1987)
	2	= Dry (1988)
FARM	1	= San Jorge
	2	= Don Benito
	3	= San Francisco
CLASS	1	= Pregnant-lactating ewe
	2	= Lamb
	3	= Yearling
NUMBER		= Animal number
HTO		= Hemetocrit, %
HB		= Hemoglobin, g/dl
LEUCO		= Leucocytes, /ul
NEUT		= Nautrophile (mature), %
LYM		= Lymphocite, %
MONO		= Monocyte, %
EOS		= Eosinophil, %
BAS		= Basophil, %

TSS	STAS	FAM	C	AS	NUMB					YR	MRN	F	E	PAS
1	1				4942	35			0	72	0			3
2	1	1		1	70	78	3..	17700	7	0	5	0		
3				1	2646	90	0..	8700	86	1				0
4				1	7677	72	9.9	72500	73	0				3
5					..432	37	9.7	16800	87	1	0	0		
6					2209	74	11.7	5100	68	0	0	0		
7			1		9			3400	78	1	0	0		
8					2670	38	0.2	25600	65	1	5	0		
9					8349	25	10 7	11761	73	4	2			
10					4810	35	7 8	70500	78	7	7			
11				1	5916	29	10 9	2 200	84	0	7	0		
12				1	7658	9	9 6	5810	77	0	2	0		
13			4	2	7030	37	17 3	14560	79	0	1	0		
14			4	2	7277	32	10 8	16800	96	0	0	0		
15			1		78134	78	12 9	74300	93	7	0	0		
16	1	1	2		76145	21	10 3	13200	96	0	1	0		
17	1		4		78.. 9	37	12 5	42000	33	1	1	4		
18	1	1			78193	76	9	18100	57	1	1	0		
19	1	1	4		7960	71	0 3	24000	37		0	2		
20	1		2		78147	75	1 7	16500	79	0	1	0		
1	1	1	2		78111	34	1 3	11350	97	0	0	0		
22	1	1	2		78171	39	11 0	7820	97	1	0	0		
2	1	1			7620	74	1 7	15300	90	1	0	9		
24	1	1	7		76154	55	..6	12500	98	1	0	0		
25	1	1	2		7243	35	0	78600	97	3	1	0		
26	1	1	5		6733	00	17 1	7854	93	0	1	0		
27	1	1	4		5413	30	11 2	24000	47	7	0	0		
28	1	3	4		5083	24	12.3	4200	97	0	0	0		
29	1	1	7		6895	77	11 6	1344	87	1	4	4		
30	1	1	3		6831	39	12 0	15000	36	0	0	0		
31	1	1	3		6417	74	11 4	9950	91	0	3	0		
32	1	1	3		5909	30	11 7	9874	95	0	0	0		
33	1	1	7		5967	79	1 4	17700	82	0	0	0		
34	1	1	7		6081	74	11 5	8794	79	0	5	0		
35	1	1	3		5229	35	11 9	1 553	85	2	2	0		
36	1	4	2		6813	38	17 1	24100	82	1	5	0		
37	1	4	1		22	44	14 4	8700	69	7	2	0		
38	1	7	1		122	39	13 0	5000	76	0	20	0		
39	1	7	1		88	37	12 3	8200	63	1	3	0		
40	1	2	1		146	40	13 3	7400	75	1	0	0		
41	1	7	1		106	37	12 3	6800	78	1	3	0		
42	1	7	1		110	46	15 3	7700	66	7	2	3		
43	1	2	1		261	75	11 6	9800	76	0	1	0		
44	1	7	1		80	44	14 5	7500	63	1	7	0		
45	1	2	1		102	39	11 6	5300	78	0	4	7		
46	1	7	1		736	43	14 3	6800	75		1	1		
47	1	2	1		78	42	14 0	6800	58	0	10	0		
48	1	2	2		212	42	14 0	8400	97	2				
49	1	2	7		7	43	14 4	7500	78	7	1	0		
50	1	7	7		134	43	14 3	9100	93	2	1	0		

	SEAS	FARM	CLAS	NUMB	YTD	HD	EUCD	LYR	MOW	HOE	B+S
1	1	?	2	79	48	».0	4500	77	_	0	0
52	1	2	2	76	41	.3 3	5300	86	3	1	0
53	1	2	2	79	36	?.6	>000	88	0	0	0
54	1	2	?	.80	42	13 3	3800	93	2		?
55	1	2	2	1.4	35	11 3	5000	87	4	?	?
56		_	3	536	44	14 6	8300	96	?	?	?
57	_	2	2	12	43	4 9	?300	57	5	1	
58	1	2		384	45	15 1	6300	94	2	0	0
59	1	2	3	31	45	15 8	7 00	76	3	0	?
60		2	3	49	32	?0 6	7900	37		_	
61	1	2	3	1 9	40	13 3	8350	81		0	0
62	1	2	3	107	39	.3 0	>500	79	?	?	0
63		?	3	111	38	12 6	5800	47	0	?	0
64		2	3	759	41	13.6	8800	95		?	0
65	1	?	3	125	39	.3 0	6200	98			0
66			3	27	39	12.9	10000	75	3	0	0
67			3	35	40	13 9	7700	31	2	0	0
68		2	3	2	46	13 1	6500	90	_	0	0
69		?	1	912	41	.2.4	5650	62	2	5	0
70		?		225	40	.3.2	7400	52	11	0	0
71				382	42	14.0	6350	57	9	0	0
72		3		277	44	14 6	10750	62	0	9	0
73				926	41	13.5	7500	40	1	12	0
74				295	40	13.3	7600	83	2	?	0
75		3		244	41	?3.6	7700	32	0	10	0
76		3	1	922	44	14.8	8600	34	0	0	0
77		3	1	731	45	15.1	8000	72	0	6	0
78			1	913	41	13.3	5400	71	3	3	0
79	1			286	41	13 6	5100	78	0	3	0
80			3	359	41	13 3	9500	60	2	?	0
81	1	?	3	726	46	15.2	7800	62	8	12	0
82	1	2	3	309	34	11 3	3900	74	5	0	0
83	1	2	3	911	36	1.7	6500	50	0	?	0
84		?	3	406	39	12 9	9500	58	3	2	
85	1	2	?	437	38	12 6	5800	64	0	_	0
86	1	3	3	217	40	13 3	6100	67	2	_	_
87		3	3	857	37	12 3	10200	66		2	0
88	1	3	3	249	35	11 6	8300	42	0	0	0
89				.05	41	13 6	7700	52	0	1	0
90	2	?	2	7818	39	14.5	7350	99	0	1	0
91	2	1	3	7821	36	12 8	6440	71	0	0	1
92	2	1	3	7837	38	12 7	6440	66	1	2	
93	2	1	3	7834	32	12 7	6800	45	0	0	0
94	2	1	3	78143	36	12 9	5300	47	1	_	1
95	2	1	3	78131	36	10.0	5650	59		4	
96	2	1	3	78153	36	10 9	5150	53	2		0
97	2	1	3	78203	36	12.2	5100	63	1	7	1
98	2	1	2	78205	42	14.3	5250	91	0	0	0
99	2	1	2	78243	42	13 6	7250	85	2	0	
00	_	1	2	78264	29	13.0	7950	79	3	2	0

OBS	EAS	FARM	CL-S	WOMB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
101	2	1	4	8279	35	[illegible]	10550	90	0	1	0
102	2	1	3	7929	47	[illegible]	9500	89	2	1	2
103	2	1	[illegible]	7952	37	3.2	7200	94	0	1	1
104	[illegible]	[illegible]	2	7667	26	3.1	7450	55	2	2	2
105	[illegible]	1	2	797	26	[illegible]	5200	76	0	4	0
[illegible]	[illegible]	[illegible]	[illegible]	7977	40	13.7	8100	68	2	3	0
[illegible]	[illegible]	[illegible]	4	8383	39	4.5	5850	90	0	1	[illegible]
108	1	1	[illegible]	7884	41	13.0	8750	75	[illegible]	0	0
109	1	1	4	7932	43	4.4	7050	88	1	[illegible]	[illegible]
110	[illegible]	[illegible]	[illegible]	9100	36	12.3	9300	92	0	0	0
111	4	1	1	5900	35	13.1	7450	55	2	1	0
112	[illegible]	[illegible]	1	5910	27	10.3	3850	72	0	2	0
113	1	1	1	5960	0	3.6	6350	78	1	4	0
114	1	1	3	7812	36	2.1	9550	63	0	2	[illegible]
115	[illegible]	1	3	7520	37	12.2	8350	48	1	0	0
116	[illegible]	1	3	7417	32	3.9	6650	59	3	3	1
117	2	1	1	4821	24	7.3	4500	92	0	0	0
118	2	1	3	7223	41	13.0	7250	63	0	12	0
119	2	1	1	340	34	0.9	3650	78	2	1	0
120	2	1	1	5879	32	10.0	11200	39	0	1	0
21	2	1	1	3916	31	10.1	6560	74	1	0	2
122	2	1	1	6614	28	7.6	9200	72	2	1	0
123	2	1	1	1916	35	13.1	4650	78	0	2	0
124	2	1	1	626	34	11.7	7900	94	2	1	0
125	2	1	1	5960	34	0.5	10750	96	2	2	0
126	2	2	2	1	39	13.1	3400	78	0	0	1
127	2	2	4	4	42	13.4	6800	78	0	3	0
128	2	2	2	3	34	12.1	8650	62	0	0	1
129	2	2	2	4	42	4	5	92	5	0	0
130	2	2	3	15	39	12.7	7200	60	4	5	2
131	2	2	2	24	34	1.3	7700	61	1	10	4
132	[illegible]	[illegible]	1	54	29	13.3	4450	77	0	5	[illegible]
133	2	2	3	78	35	11.9	6450	58	2	4	1
134	2	2	3	80	44	11.1	6500	55	0	0	0
135	2	2	[illegible]	55	34	12.6	3850	80	0	7	[illegible]
136	2	2	[illegible]	44	43	16.0	2600	51	2	3	[illegible]
137	2	2	3	86	42	14.9	5700	58	1	0	0
138	2	2	3	15	34	11.4	4900	73	1	0	[illegible]
139	2	2	1	26	47	15.9	5800	77	0	1	1
140	2	2	3	37	33	11.1	4250	57	0	0	0
141	2	2	3	147	41	14.2	4150	73	2	9	0
142	2	2	3	50	39	12.0	4650	67	3	4	0
143	2	2	3	51	32	10.5	7150	73	2	1	1
144	2	2	3	52	39	12.0	8750	56	2	2	1
145	2	2	3	54	39	13.3	5000	82	1	0	1
146	2	2	3	63	31	10.2	3300	97	0	0	0
147	2	2	3	170	33	11.0	8500	72	2	3	1
148	2	2	3	188	38	12.2	5500	74	1	2	0
149	2	2	3	192	38	13.0	5000	74	1	1	[illegible]
150	2	2	3	203	42	13.6	10300	72	0	1	1

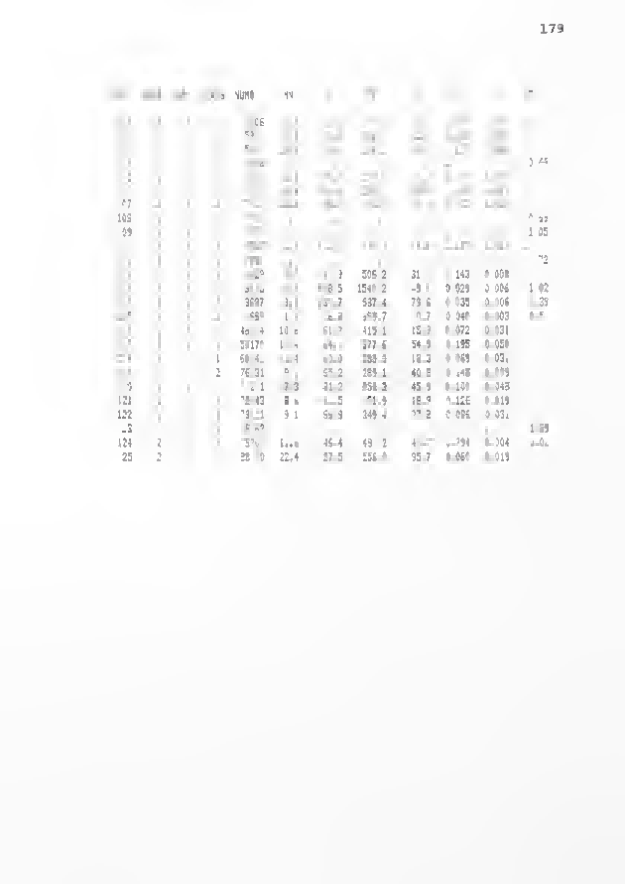
OBJ	SEAS	FAM	CLAS	VOLM	HT0	40	LEUCN	LYM	MON	E00	GAS
131	7	?	7	473	34	7.1	3500	6[illegible]	2	3	1
152	2	?	3	791	37	12.0	6250	57	3	0	
153	7	?	3	707	36	13.4	8250	91	2	1	0
34			1	1170	35	2.7	6330	53	2	1	1
33		3	7	[illegible]	47	16.6	2950	4[illegible]	3	1	2
56	?	3	?	3	47	16	3400	43	0	1	
157	7	3	7	3	40	13.6	2800	74	0	0	A
58	7	3	4	6	41	13.7	3430	14	3	0	
139	2	3	1	137	34	11.3	4300	57	2	1	2
160	7	3	3	225	40	10 7	5700	31	6	10	0
161	7	3	1	226	40	13 0	6100	64	0	17	0
162	2	3	1	233	44	13.0	6500	58	2	11	2
163	7	3	1	224	29	8.8	3200	73	1	4	0
164	2	3	1	736	34	9 0	4900	87	0	6	6
165	7	3	1	747	36	12 0	6000	71	0	3	1
166	7	3	1	746	39	10.3	4600	93	0	6	0
167	7	3	3	316	41	13.0	4600	75	2	1	0
168	2	3	3	331	36	13.2	4104	82	0	3	0
169	2	3	?	[illegible]6	37	11.3	3400	70	0	1	0
170	2	3	3	357	37	13.4	5500	74	0	1	0
171	2	3	3	358	41	14.0	4300	91	0	2	1
177	2	3	3	372	41	14.0	8550	46	7	2	1
172	7	3	3	375	36	11.3	6500	84	0	1	0
174	2	3	1	421	35	11 0	5400	76	1	6	1
173	2	3	1	434	47	17 0	5[illegible]30	63	0	6	0
178	2	3	1	437	41	12 3	3400	31	2	3	0
177	7	3	3	604	41	13 3	3200	90	0	4	1
178	7	3	3	606	31	11 1	4500	82	0	1	0
179	7	3	3	613	41	14.0	4300	78	1	1	0
180	7	3	3	643	36	13-9	4900	71	1	11	7
181	7	3	3	713	47	14 7	4400	74	1	3	0
187	?	3	3	716	36	11 3	3700	74	0	0	0
183	7	3	3	725	47	17.3	4800	86	0	3	0
184	7	3	3	741	42	13.4	4334	90	0	0	6
185	7	3	3	747	40	3.8	3300	63	0	1	0
186	7	3	3	758	37	13.8	4200	34	0	1	2
187	2	3	3	763	44	14.3	3500	87	0	0	0
188	2	3	3	769	39	13 7	3550	73	0	4	0
189	7	3	3	772	41	13.6	3800	48	0	6	0
190	2	3	3	777	44	13 3	4250	83	0	1	6
131	2	3	7	779	40	7 7	4400	84	0	0	6
197	7	3	3	809	31	9 7	5800	83	0	7	0
193	2	3	1	906	33	13 3	5650	69	0	7	0
194	7	3	3	5006	40	14 3	2900	70	7	6	0

LIVER DATA CODES

OBS		= Observation number
SEASON	1	= Rainy (1987)
	2	= Dry (1988)
FARM	1	= San Jorge
	2	= Don Benito
	3	= San Francisco
CLASS	1	= Pregnant-lactating ewe
	2	= Lamb
	3	= Yearling
NUMBER		= Animal number
MN		= Liver manganese, ppm dry matter
ZN		= Liver zinc, ppm dry matter
FE		= Liver iron, ppm dry matter
CU		= Liver copper, ppm dry matter
CO		= Liver cobalt, ppm dry matter
MO		= Liver molybdenum, ppm dry matter
SE		= Liver selenium, ppm dry matter

| | | |

								FE				NB	
								494 6	42.5	0 067	0 030		0
				78				54 8			0 0 4		
				35				01 8			0 079		
								54 0	33		0 05a		
								506					
								95 5					
								2.1		044			
								5 5					
								2a 3	254 5	0 245			
								.45 6	38	0 050	0 331	0 67	
								.94	80 3	0 2	0 034		
								16 2	.53 5	0 025	0 034	0 87	
				.34	5 7	19.4		324.0	64.3	0 026	0 025		
				36	7	94.1		95 4	336 2	0 013	0 037	0 74	
				1		6		170.9	45.5	0.031	0 034	0 33	
					7.5	01 2		259 E	1.1 D	0 025	0-030		61
				3o1		03.3		339	101 6	0 002	0 025	0 33	
				5	7	77		174 4	75	0 015	0 009	0 77	
				37		72.0		253 2	105	0	0 010		38
				50		92.5		276 5	246 3	0 039	0 039		03
				7				252 9	5	0 023	0 022		22
				5	9 4				131 2	0 025	0 038	1	40
				43	7	06.1		380 9	58 7	0 054	0 034	0	7
				45	7 3	56 5		209 6	188 5	0 034	0 037	1	02
				73	4 5	87 6		66	3	0 156	0 056		
				04	7	5			117 5	0 038	0 022	1	32
				508	10 1	140 7		1031 5	223 3	0 021	0 036	0	75
				10	7	73 7		330 5	143 9	0 023	0 026		
79				15	9	38		100 8	47 9	0 035	0 006	0	50
80				5	9 6	6 7		344 2	76 5	0 051	0 021		29
3				703	7	82.5		94 4	71	0 034	0 010		
82				5	12.3	8 1		206	57 3	0 032	0 027	1	45
83				716		104 5		1 2	69 2	0 032	0 034	1	14
84				717	9 9	00 7		303 7	56 3	0.029	0 030		02
85				725	8 3	33.5		527	15	0 03	0 025		99
86				741	0.4	62.5		270 4	133 6	0-025	0 026	0	60
87				747	1 4	54 5		221 6	191 2	0 036	0 025		
88				756	7 7	56.6		313 3	54 2	0 030	0 025	0	72
89				5	12.4	66.3		416 5	114	0 004	0-011	0	64
90				769	12 0	55.6		259 1	109 2	0 035	0 026	1	49
91				772	0.2	80 5		381 7	67 6	0 050	0 029	1	55
92				777	0 2	57.2		264 3	4	0 034	0 025		09
93				779	1	50 5		205 4	102 7	0 020	0 033	0	54
94				809	11 2	79.0		26 7	43 3	0 061	0 011	1	31
95				986								0	32
96				1000	0 0	64.0		370 4	63.1	0 016	0 014	0	78
97				1916	13 9	55 9		320 8	76.7	0 209	0 061		
98				2040								1	01
99				3916								0	32
100				5000	7 5	132 0		1506 2	208.2	0 109	0.022		



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BIOGRAPHICAL SKETCH

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With the support of a scholarship from Instituto Colombiano Agropecuario, he enrolled in August 1986 in the Graduate School at the University of Florida and is a Ph.D. candidate.

He is married to Diana Herrera de Pastrana and has five children, Diana Constanza, Gloria Consuelo, Maria Paola, Rodrigo Jose and Ian Gabriel.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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